SEWAGE AND INDUSTRIAL WASTES

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

Metropolitan Sewage Problems—Coulter et al.

Automotive Wastes—Balden

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DO Needs of Fish—Davison et al.

ABS Removal in Sewage Treatment—McGauhey and Klein

Operator's Corner

Illustrated Refinery Story

AUGUST 1959—VOL. 31, No. 8

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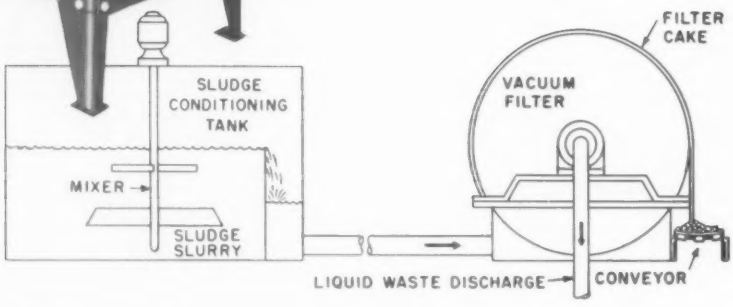

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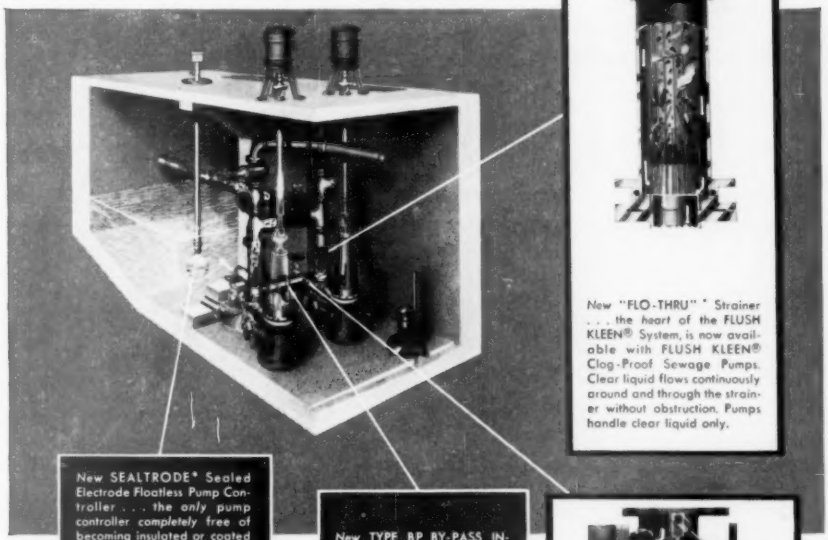

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Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 31 **August 1959** **Number 8**

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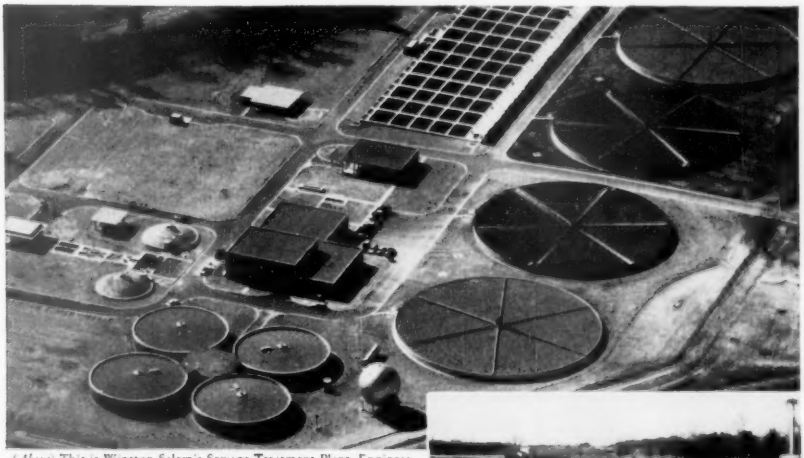

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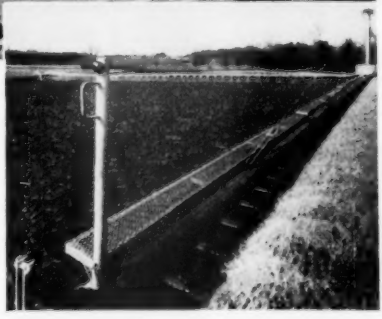

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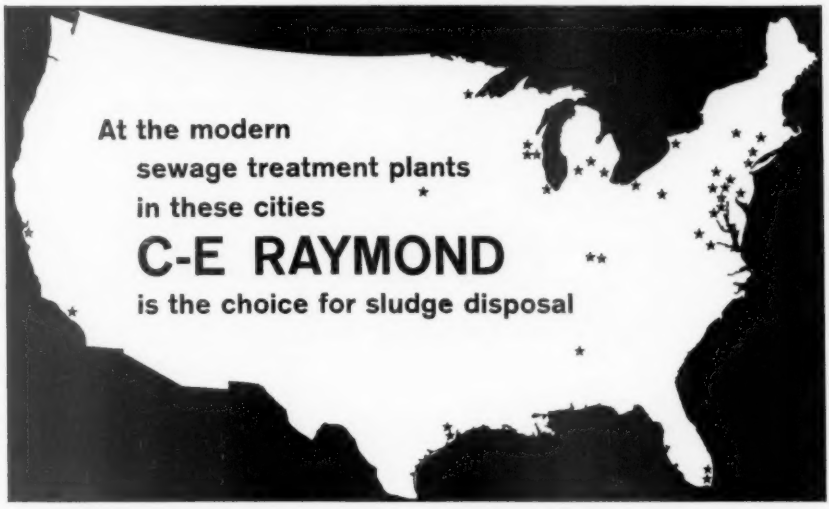

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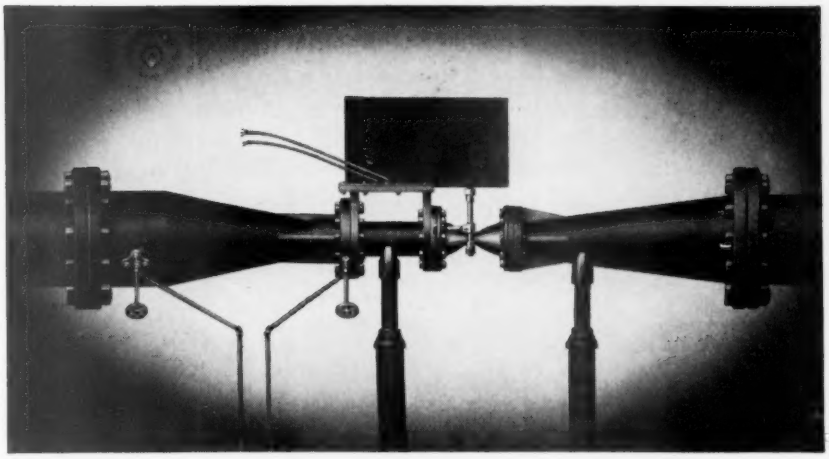

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Association	*Place*	*Time*
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New Zealand Sewage and Industrial Assn.	Auckland, New Zealand	Sept. 1–2, 1959
South Dakota Water and Sewage Works Conf.	Marvin Hughitt Hotel Huron, S. Dak.	Sept. 2–4, 1959
Rocky Mountain Sewage and Industrial Wastes Assn.	Jackson Lodge Jackson, Wyo.	Sept. 8–10, 1959
Georgia Water and Sewage Assn.	Georgia Inst. of Technology Atlanta, Ga.	Sept. 9–11, 1959
Kentucky-Tennessee Industrial Wastes and Sewage Works Assn.	Lafayette Hotel Lexington, Ky.	Sept. 14–16, 1959
North Dakota Water and Sewage Works Conf.	Dacotah Hotel Grand Forks, N. D.	Sept. 23–25, 1959
Missouri Water and Sewerage Conf.	President Hotel Kansas City, Mo.	Sept. 27–29, 1959
Canadian Institute on Sewage and Sanitation	Royal York Hotel Toronto, Ont.	Sept. 28–30, 1959

THIRTY-SECOND ANNUAL MEETING

Federation of Sewage and Industrial Wastes Associations
Host—Sewage and Industrial Wastes Section,
Texas Water and Sewage Works Association
Statler Hilton Hotel, Dallas, Texas

Technical Meetings and Exhibits—Dallas Memorial Auditorium
October 12–15, 1959

New England Sewage and Industrial Wastes Assn.	Biltmore Hotel Providence, R. I.	Oct. 21–22, 1959
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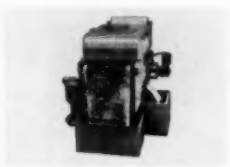
SEDIFLOTOR® Clarifier combines flotation and sedimentation in one compact unit. Particularly effective for the treatment of wastes containing greases, oils and light suspended solids. Provides maximum capacity in locations where space is limited.

Bulletin 6051



IMPINJO® Filter cuts production costs and saves money on any metal-working operation using coolants or cutting oils. Removes metallic and non-metallic solids. Reduces rejects, lengthens tool, wheel or abrasive belt life, saves coolant and minimizes waste disposal problems.

Bulletin 9020-A

INFILCO

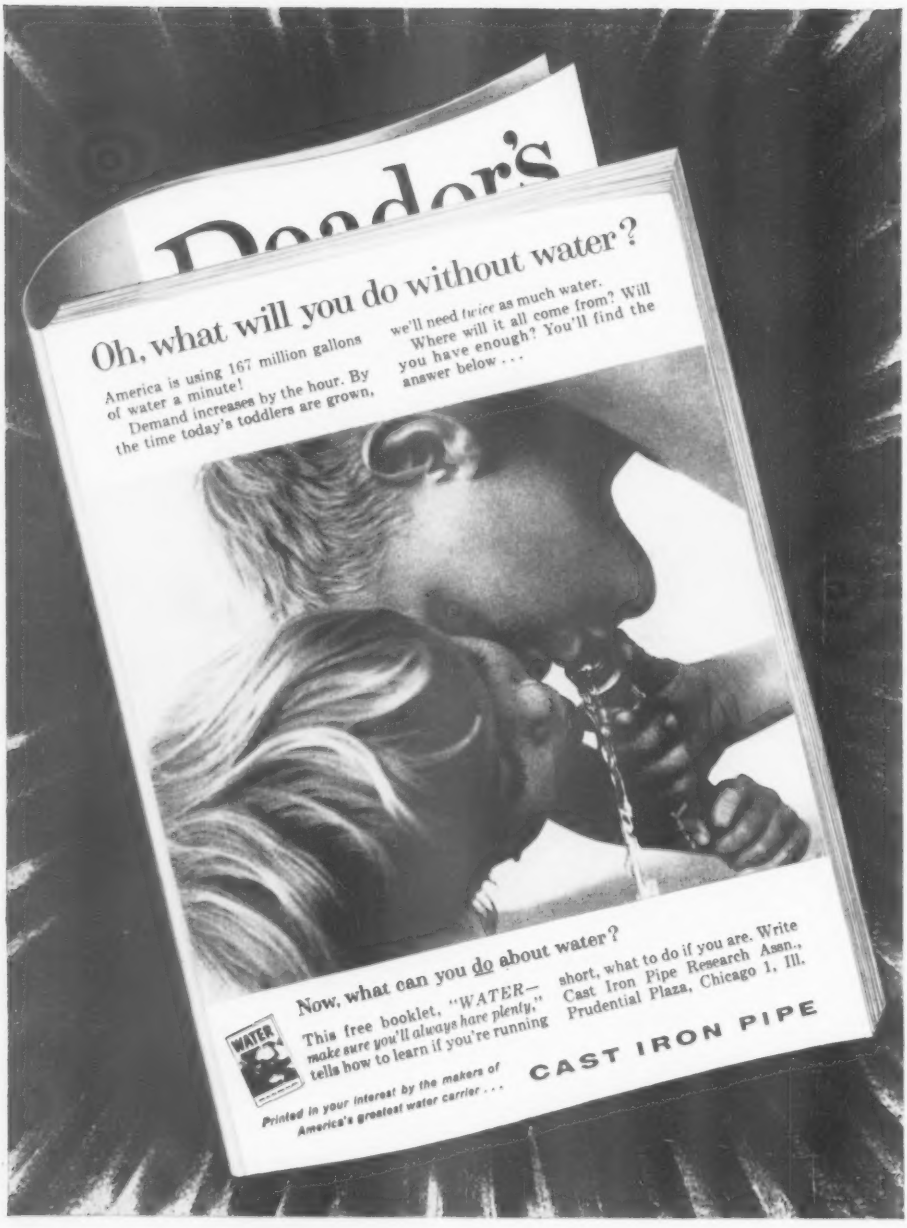
INFILCO INC.

General Offices: Tucson, Arizona

Field offices throughout the United States and in other countries

INFILCO can help you and your engineer evaluate any industrial waste disposal problem.

Write today for Bulletin 80-A for a complete listing of INFILCO equipment.


Reader's
Oh, what will you do without water?
America is using 167 million gallons of water a minute!
Demand increases by the hour. By the time today's toddlers are grown, we'll need twice as much water.
Where will it all come from? Will you have enough? You'll find the answer below . . .
Now, what can you do about water?
This free booklet, "WATER—make sure you'll always have plenty," tells how to learn if you're running short, what to do if you are. Write Cast Iron Pipe Research Assn., Prudential Plaza, Chicago 1, Ill.
WATER
Printed in your interest by the makers of America's greatest water carrier . . .
CAST IRON PIPE

New Ad Campaign in Reader's Digest Dramatizes America's Water Problem

Cast Iron Pipe Research Association promotes better understanding of water supply and distribution problems

Offers Informative Booklet for Step-by-Step Action at the Local Level

Here's help for you and everyone else directly concerned with the supply, treatment and distribution of water—help that will acquaint the people in your town with the vital importance of this growing problem.

On the opposite page you see the first in a series of advertisements, this one appearing in February *Reader's Digest*. Placed by the Cast Iron Pipe Research Association, these striking advertisements point out to Mr. and Mrs. America how much we depend on a good water system and why we can no longer take it for granted.

Similar advertising will appear regularly this year in *U. S. News & World Report, Nation's Business, Better Homes & Gardens, American Home* and *Sunset* magazines to carry this public service message to millions of community leaders and homeowners.

Free Local Plan-of-Action Booklet

These ads offer a free booklet telling about the water problem. It shows how responsible citizens can acquaint themselves with the needs of their community. It also gives a step-by-step outline of action, telling how they can help their officials extend and improve the local water system through more adequate rate structures or financing.

We'll be happy to send you a free copy of this new booklet. Write to Thos. Wolfe, Managing Director, Cast Iron Pipe Research Association, 3440 Prudential Plaza, Chicago 1, Ill.

Three reasons why cast iron pipe is America's greatest water carrier:

1. More miles of underground cast iron water mains are now in use than of all other kinds of pipe combined.

2. More miles of cast iron water mains are now being purchased and laid than of any other kind of pipe.

3. Impartial surveys prove that today's water utility officials and consulting engineers prefer cast iron pipe for underground water distribution by an overwhelming majority.

CAST IRON PIPE

THE MARK OF THE 100-YEAR PIPE

Cleans up to 120 feet of sludge bed per hour

Mechanical cleaner provides faster and more efficient sludge removal than conventional hand cleaning methods

Here's a mechanized method of cleaning sludge beds that will pay for itself in a relatively short time. While individual savings depend on such variables as size of plant, available manpower, method of disposal, etc., annual savings of 60% have been reported over conventional hand cleaning.

The sludge bed cleaner offered by Link-Belt is essentially a conveyor system on wheels . . . the system is mounted on a standard tractor, which travels on concrete runways in sand beds and cleans a path up to 26 feet in width. Performance-proven Link-Belt conveying and power transmission components are combined into an efficient mechanism that is operated by hydraulic motors.

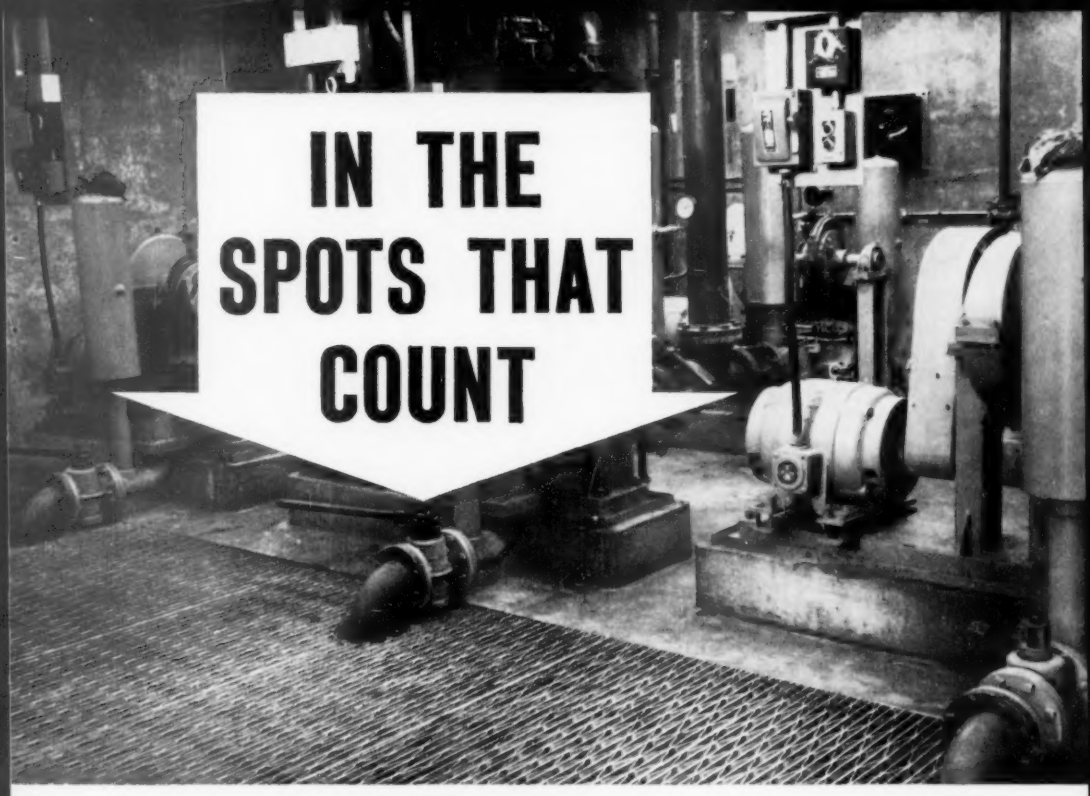
The cleaning cycle works like this. Forked scoops assure minimum loss of filter bed sand. The scoops are raised alternately, elevating the sludge and chuting it over a front truss. Sludge is conveyed by two wing conveyors into a trough where it is pushed along by a center longitudinal flght conveyor. This conveyor carries the sludge up a 45° incline where it is deposited in a truck that is towed or driven behind the tractor.

For more detailed information on how you can clean sludge beds faster, more efficiently, call your nearest Link-Belt office. Send for Folder No. 2671.

LINK-BELT

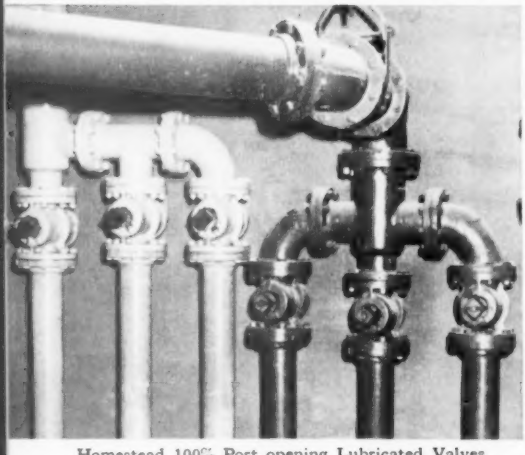
SANITARY ENGINEERING EQUIPMENT

LINK-BELT COMPANY: Executive Offices, Prudential Plaza, Chicago 1. Sanitary Engineering Regional Offices—Colmar, Pa., Chicago 9, Kansas City 8, Mo., San Francisco 24. Sales Offices in All Principal Cities. Export Office, New York 7. Representatives Throughout the World. 14.982



IN THE SPOTS THAT COUNT

Cedar Rapids Sewage Plant prefers Homestead 100% Port Opening Valves



Homestead 100% Port opening Lubricated Valves controlling supernatant, sludge and gas in Cedar Rapids Sewage Plant.

In the transport of sludge and grease from settling basins, full pipe area lines are essential to long pump life. That's why Howard R. Green Company, Engineers, specified 95-4", 15-6", and 9-8" Homestead Lubricated Plug Valves in this Iowa sewage treatment plant. Homestead's 100% pipe area design guarantees full flow—no restrictions to put a strain on pumps and motors.

Add positive lubrication and sealing, Homestead's leakproof no-stick design, plus minimum maintenance, and you'll know why Superintendent William J. Meaney says, "I'm fully satisfied with Homestead Valves on our lines."

Mail coupon today for Reference Books 39-1 and 1A—a complete library of Homestead Lubricated Plug Valves and their uses.

Please send me complete data on Homestead Lubricated Plug Valves and their suggested uses.

Name..... Title.....

Company.....

Address.....

City..... Zone.... State.....

hv

HOMESTEAD VALVE MANUFACTURING COMPANY

P. O. Box 48, Coraopolis, Pennsylvania

Sewer corroded by H_2S replaced with Armco SMOOTH-FLO Pipe

Part of a 12-year-old rigid pipe sanitary sewer in Sacramento, California, had been eaten away by hydrogen sulphide gases. The resulting seepage undermined the sewer foundation, causing the pipe to settle and crack.

To withstand the corrosive gases and to maintain good alignment in the unstable foundation, engineers specified Armco SMOOTH-FLO® Sewer Pipe as a replacement.

Armco SMOOTH-FLO Pipe has the proved durability and strength of corrugated metal pipe, plus a smooth interior lining for high flow capacity. Its long lengths and positive joints enable SMOOTH-FLO to maintain good alignment even in unstable soils. For complete details on Armco Sewer Structures write to Armco Drainage & Metal Products, Inc., 4839 Curtis Street, Middletown, Ohio.

ARMCO DRAINAGE & METAL PRODUCTS

Subsidiary of ARMCO STEEL CORPORATION

OTHER SUBSIDIARIES AND DIVISIONS: Armco Division • Sheffield Division
The National Supply Company • The Armco International Corporation
Union Wire Rope Corporation • Southwest Steel Products

SEWER TO TRUCK IN 60 SECONDS!

PAT. PENDING

Sewer Cleaning with a TRUCK-LODER OBSOLETES THIS

DUMPING RAW SEWAGE IN THE STREET

SHOVELING RAW SEWAGE INTO THE TRUCK

- It's Faster!
- It's Safer!
- It's More Sanitary!

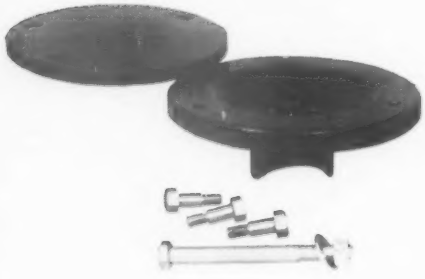
FLEXIBLE INC.

3786 DURANGO AVE., LOS ANGELES 34, CALIF.
1005 SPENCERVILLE ROAD, LIMA, OHIO
351 W. JEFFERSON BLVD., DALLAS, TEXAS

End clogging and

maintenance problems with

EIMCO-PROCESS NON-CLOG DIFFUSERS



Applicable to any aeration requirement, Eimco-Process Non-Clog Diffusers provide even distribution of finely divided air bubbles without the common problems of reduced air flow due to a collection of foreign matter or complete clogging causing plant operational difficulties. They create a wide band of aeration with a continued, uniform pattern, thus giving greater transfer efficiency and avoiding any dead zones which might allow particles to deposit in the tank.

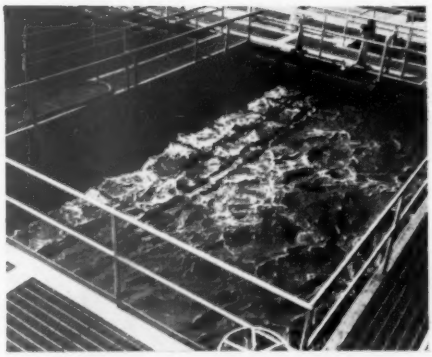
The diffuser consists of a special cone with a flat annular top surface. The top plate is designed to move up slightly under proper air pressure, with guide bolts providing alignment, allowing the air to escape in fine bubbles. If the air pressure is reduced, the plate quickly comes to rest on the top surface of the base casting, thereby preventing any clogging by foreign solids. In addition, the diffuser is not subject to internal clogging from air impurities, compressor oil or header scale.

Maintenance time and replacement expense are practically eliminated by this Eimco-Process design innovation. No back-flushing is necessary and the mechanical action of the raising and lowering of the cover effectively prevents encrustation around the annular orifice.

Eimco-Process Non-Clog Diffusers are readily adaptable to any type of installation. A saddle cast into the cone fits over a hole drilled in the header and the diffuser is securely anchored by a locking bolt. Horizontal alignment can be made before tightening the locking nut after which no movement is possible.

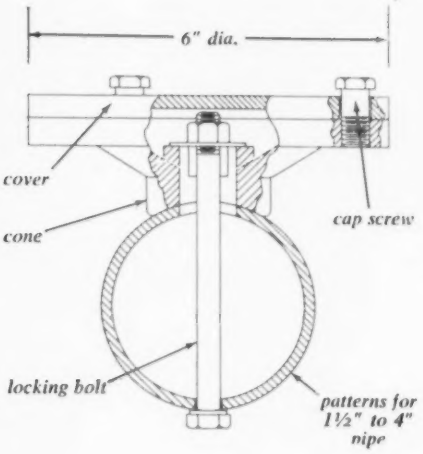
The diffusers are 6″ in diameter with cone patterns for standard pipe sizes from 1½″ to 4″. They can be furnished separately or assembled on headers and are also available flushed and tapped to replace threaded diffusers.

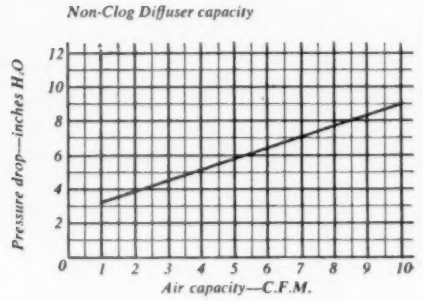
Non-Clog Diffusers are competitively priced and normally available from stock. We will be pleased to quote on your requirements or have a representative call…our applications engineers and nation-wide sales organization are at your service



Note uniformity of roll and absence of dead zones in this aeration tank equipped with Non-Clogs.

Unretouched photo of four Non-Clog Diffusers after a year of service under extremely corrosive conditions at the South San Francisco Sewage Treatment Plant. In this field trial, 10 Non-Clog Diffusers replaced 19 ordinary nozzle-type diffusers which had to be back-flushed at least twice a week and replaced every three months. During their year of service, the Non-Clog Diffusers performed at rated capacity without ever being backflushed or otherwise maintained. Following this trial, the plant standardized on Non-Clogs for all pre-aeration equipment.





This chart indicates the low head loss inherent in the Non-Clog design . . . lower than that of any nearly comparable diffuser. Due to this high performance, desired air flow can usually be obtained with fewer diffusers. In addition, transfer efficiency does not drop, and over a long period of operation, Non-Clog Diffusers will perform with greater overall efficiency.

THE EIMCO CORPORATION

B-467

Process Engineers Division
420 Peninsular Avenue
San Mateo, California

Attractive, Corrosion-Resistant Glazed-Tile
Effluent and Water Treatment Tanks

Exacting Design —
Meticulous Workmanship

As the final step of construction, Stebbins workmen carefully wash down the exterior of the tanks with acid.

In this view of tank floors under construction, note the clean, smooth joints – the mark of good workmanship. Note the variety of tile shapes. Horizontal and vertical steel reinforcing is shown in the walls which will be solidly filled with concrete as work progresses.

Complete Service —
Design, Installation, Maintenance

WRITE FOR BULLETIN AET-59

SEMCO

STEBBINS Engineering and Manufacturing Company

WATERTOWN, N. Y. • PENSACOLA, FLORIDA

STEBBINS ENGINEERING CORP. — TOWER BLDG., SEATTLE, WASH.

CANADIAN STEBBINS ENGINEERING & MANUFACTURING CO., LTD.

TOWN OF MOUNT ROYAL, MONTREAL 9 • MERCHANT EXCHANGE BLDG., VANCOUVER

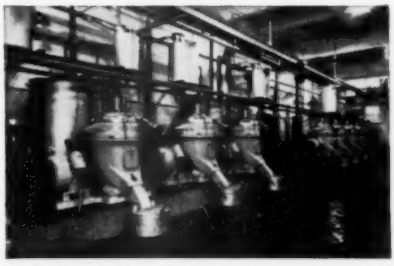
SINCE 1884

Specialists in Design, Installation and Servicing of Linings and Tile Tanks

FLUIDICS

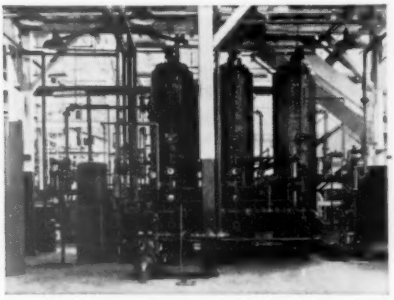
is a Pfaudler Permutit program providing

the know-how
the equipment
and the experience
for solving problems
involving fluids

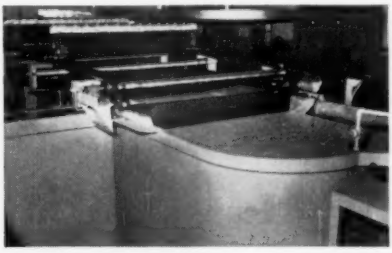


Dewatering Sludges. Titan Centrifuge exerts settling power up to 7800 times gravity. Concentrates slimes and clarifies liquids. Precisely separates two liquids and a solid in a single pass. Dewaters plating wastes, protein fines and flocculent precipitates. Recovers oil from tank bottoms, fat from waste, and pulp from white water. Saves product, filter aid, power and maintenance.

FOR WASTE TREATMENT, the Fluidics program provides a wide range of specialized equipment and technical service to help you efficiently recover valuable materials and easily dispose of unwanted wastes.



Purification of liquids and recovery of dissolved minerals from plating solutions, pickling baths, textile wastes, process solutions and similar fluids are assured with unique effectiveness by Permutit Ion Exchangers. Recovery of valuable materials often pays for equipment within a short time.

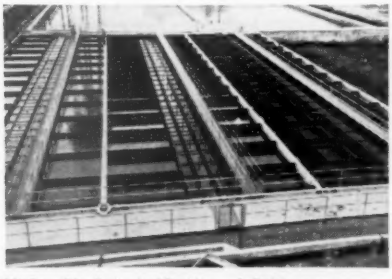


Flotation clarification of fluids containing fats, oils, greases, organics and colloidal suspensions is done quickly, effectively and economically with the Permutit Colloidair Separator.

Add to this equipment our Simplex meters and flow controllers, Permutit chemical feeders, filters and vacuum degasifiers, Ranarex CO_2 indicators and recorders, and Pfaudler evaporator systems, and you get an idea of the scope of this program in just the waste treatment area of fluid processing. Yet Fluidics is a program that provides more than just equipment. You can get complete engineering assistance as well as expert advice based upon more than 50 years' experience in fluid waste control.

For more information on how Fluidics can help in your waste treatment program, contact our Permutit Division, 50 West 44th Street, New York 36, N. Y.

In Canada: 207 Queen's Quay W., Toronto 1, Ontario.



Sludge blanket clarification of fluids requiring removal of suspended solids such as fly ash, precipitates, turbidity, etc. is accomplished with high efficiency by the Permutit Precipitator.

PFAUDLER PERMUTIT INC.

Specialists in FLUIDICS . . . the science of fluid processes

DANGEROUS WATER. Not long ago, faulty sewage disposal too often contaminated lakes and rivers... made them unfit for bathing, drinking or fishing.

MODERN SEWERAGE SYSTEMS, in which cast iron pipe and fittings are used, play a major role in keeping America's water clean, pure and wholesome... safe for bathing and drinking.

U.S. cast iron PIPE

FOR WATER, SEWERAGE AND

U. S. PIPE AND FOUNDRY COMPANY

but better than ever today!

Exacting quality checks from mine to main assure U. S. Pipe dependability

With leadership goes responsibility . . .

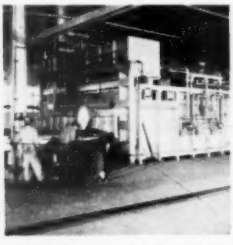
Cast iron pipe, for example, long recognized as America's basic water carrier, must be dependable and long-lived.

U. S. Pipe makes sure it is. By constantly checking and rechecking its pipe from start to finish . . . from mining to final casting.

The water officials who do such fine work planning and protecting the nation's water supply can be sure of this:

In U. S. cast iron pipe they have a fine ally to work with.

COKE being discharged on coke wharf, has been made in our modern ovens from carefully blended mixture of coals obtained from U.S. Pipe mines.

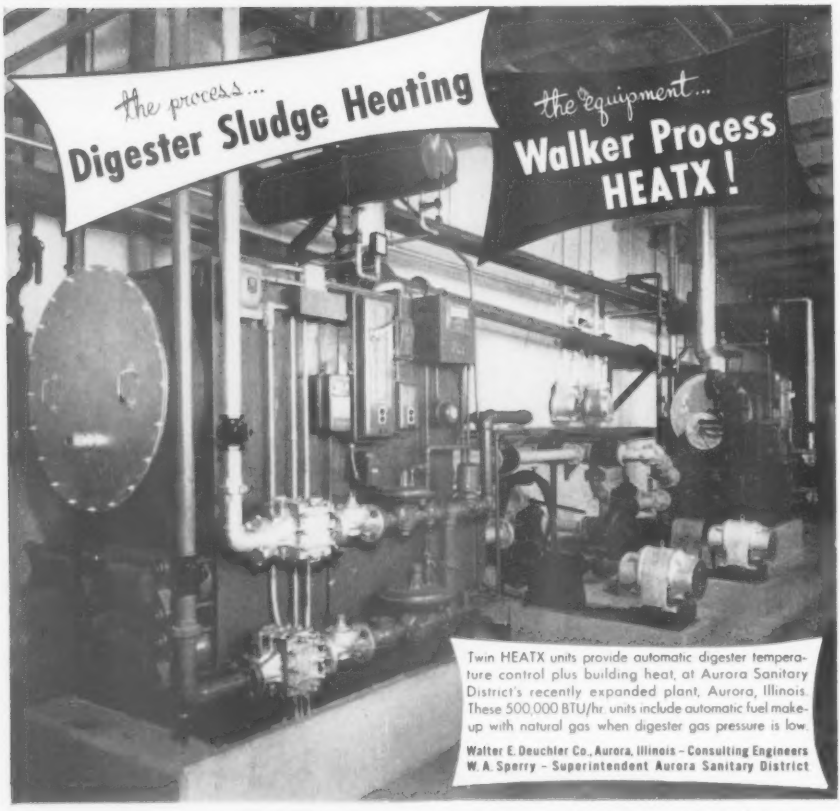


HOT PIPE is inspected and weighed before entering the heat treating furnace. Each length of U. S. Pipe is subjected to temperatures automatically controlled for uniformity.

THE SPECTROGRAPH is used by U. S. Pipe to make timely and accurate chemical determinations . . . one of many quality checks that assure top performance of U. S. Pipe.

INDUSTRIAL SERVICE CAST IRON

Birmingham 2, Ala. *A wholly integrated producer from mines and blast furnaces to finished pipe.*


the process...
Digester Sludge Heating
the equipment...
Walker Process
HEATX!
Twin HEATX units provide automatic digester temperature control plus building heat, at Aurora Sanitary District's recently expanded plant, Aurora, Illinois. These 500,000 BTU/hr. units include automatic fuel make-up with natural gas when digester gas pressure is low.
Walter E. Deuchler Co., Aurora, Illinois – Consulting Engineers
W. A. Sperry – Superintendent Aurora Sanitary District

Automatic digester temperature control ■ 180°Boiler heat for building heat

HEATX

140°Exchanger temperature prevents sludge caking
Adaptable to waste heat utilization
Exclusive rifled sludge return bend castings

Maximum efficiency using digester gas and/or natural gas or fuel oil

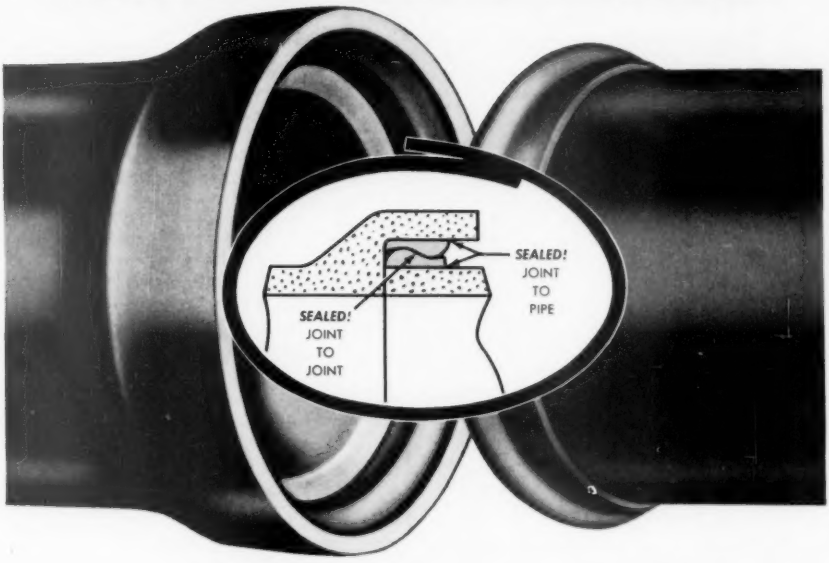
The Walker Process HEATX provides the *complete unit* for your digester sludge heating process. Concentric tube heat exchanger, fire tube boiler and control panel are combined to give absolute control over each function. Exclusive ***rifled*** sludge return bend castings cause sludge to spiral through the exchanger tubes – better K value – wall scouring prevents slime and grease adhesion. ■ The HEATX is available in standard sizes ranging from 100,000 to 2 million BTU/hr. output. Bulletin 24 S82 gives complete description of type EB (with boiler) and type E (without boiler).

WALKER PROCESS

WALKER PROCESS EQUIPMENT INC.
FACTORY • ENGINEERING OFFICES • LABORATORIES
AURORA, ILLINOIS

Wedge-Lock®

HANDLES INFILTRATION!



ROOT-TIGHT SEAL!

Patented Wedge-Lock Joints are bonded to Vitrified Clay Pipe—*at the factory*—to bring you the highest performance standards . . . the lowest installation costs.

One simple, easy operation and the joint's tightly sealed around the full pipe circumference . . . stays in continuous compression for the life of the pipe.

MINIMUM INFILTRATION!

When you specify Wedge-Lock, you reduce infiltration and resist root problems before they start . . . keep installation costs down . . . benefit from the guaranteed performance of the world's longest-lasting pipe.

Write to listed manufacturers for literature or an actual Wedge-Lock demonstration

Wedge-Lock CLAY PIPE

THE FACTORY-JOINTED CLAY PIPE AVAILABLE NATIONALLY FROM LOCAL MANUFACTURERS

Order Wedge-Lock from any of these Vitrified Clay Pipe Manufacturers:

Cannelton Sewer Pipe Company Cannelton, Ind.

The Clay City Pipe Company Uhrichsville, Ohio

The Evans Pipe Company Uhrichsville, Ohio

Graff-Kittanning Clay Products Worthington, Pa.

Larson Clay Pipe Company Detroit, Mich.

The Logan Clay Products Company Logan, Ohio

The Robinson Clay Product Company Akron, Ohio

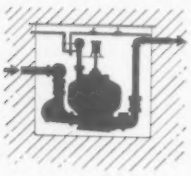
The Stillwater Clay Products Company Cleveland, Ohio

Superior Clay Corporation, Uhrichsville, Ohio

WLC-159-186-B

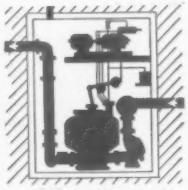
Which sewage lift station is best for your job?

TOPS IN DEPENDABILITY AND SAFETY



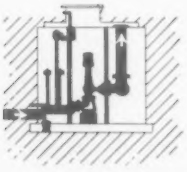
Concrete or steel underground station with Shone® Type S pneumatic ejector, mechanically controlled (warranted 25 years). Remote air supply. Nothing electrical; maintenance free; operates even under water. For municipalities and large subdivisions.

SUPRISINGLY VERSATILE, INEXPENSIVE



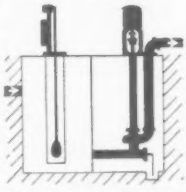
Shone® Type SAC station, underground in concrete vault. Mechanically controlled ejector (warranted 25 years) has its own compressor. Frequently less costly than package stations. Finds use everywhere.

PACKAGE STATION



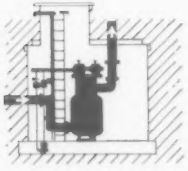
Quality underground station with vertical, short-coupled (Series 6260), dry pit centrifugal pumps. Quality design and equipment give good service life at nominal cost. For small permanent stations, growing areas.

LOW FIRST COST—EASY INSTALLATION



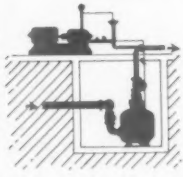
Two-compartment steel basin with centrifugal vertical wet pit pump. Pumps are not submerged; motors protected from flooding. Low first cost; fast installation. For buildings, small growing subdivisions.

ULTIMATE IN PACKAGE DESIGN



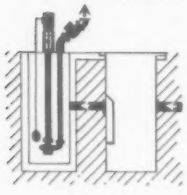
Package underground station with Expelsor® pneumatic ejector, electrode controlled. Sanitary and dependable, low maintenance, easy to service. Recommended for municipal and subdivision applications.

BUILDING TYPE STATION



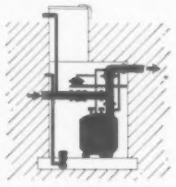
Expelsor® pneumatic ejector station designed for use in buildings. Compressor is on basement floor; ejector on floor below. Sealed installation gives safe, odorless handling of sewage indoors.

SPECIAL PROBLEMS?



Centrifugal vertical wet pit pumps with adjoining settling basin. Good for areas where sand or old sewers create problems. Special pump construction for abrasive or corrosive conditions, industrial wastes.

MAXIMUM RELIABILITY—MINIMUM SPACE



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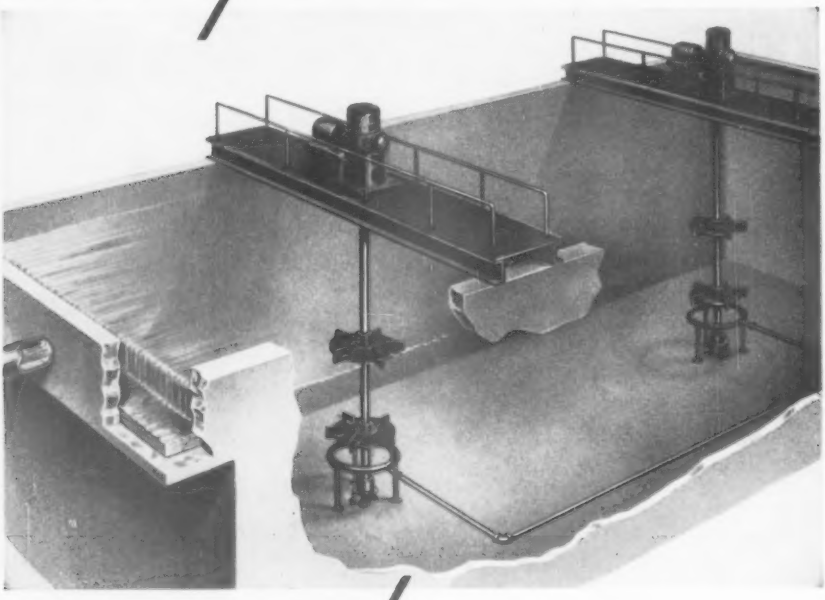

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Sewage Works

REMOVAL OF ABS BY SEWAGE TREATMENT

By P. H. McGauhey and Stephen A. Klein

University of California, Berkeley, Calif.

This is a progress report which includes the results of a major portion of a four-year study undertaken by the Sanitary Engineering Research Laboratory of the University of California and sponsored by the Association of American Soap and Glycerine Producers. This paper combines reports given by the authors at the California Sewage and Industrial Wastes Association Annual Meeting in Stockton, April 23–26, 1958; and at the 31st Annual Meeting of the Federation of Sewage and Industrial Wastes Associations in Detroit, Mich., October 6–9, 1958.

During recent years it has become increasingly evident that the general characteristics of municipal sewage in the United States have changed significantly. Steadily growing per capita use of water in homes and in industry has resulted in more dilute concentrations. At the same time the composition of sewage has been altered by many factors such as the widespread installation of home garbage grinders and the increasing production and consumption of new commercial products. Prominent in this latter category are surface active agents, especially alkyl benzene sulfonate (ABS), now extensively and increasingly used in household cleansing.

As with any new complex product which finds its way into sewage, it becomes important to know whether the presence of ABS in foreseeable concentrations will interfere with the ability of a sewage treatment plant to perform its design function. Further, it is important to know whether any ABS which may survive sewage treatment will interfere with reclamation of the plant effluent either for direct reuse or for ground water recharge. If ABS removal becomes one of the objectives of sewage treatment, it should be learned how such removal may be accomplished. This interest in the interrelationships between ABS and sewage treatment is shared alike by the engineering profession and the detergent industry for quite obvious reasons.

This paper represents a progress report on some aspects of research growing out of the mutual interest of sanitary engineers and producers of surfactants in the fate of ABS in wastewaters. Specifically, it concerns results of studies of the removal of ABS by sewage treatment processes, begun in 1955 by the Sanitary Engineering Research Laboratory of the University of California under the sponsorship of the Association of American Soap and Glycerine Producers.

Purpose and Scope of Investigation

The principal objective of the investigation was to employ such analytical methods and techniques as experiments demonstrated to be appropriate, to determine the ability of sewage treatment processes to remove or destroy detergents, as well as the ability of de-

tergents to interfere with such processes.

Inasmuch as ABS is the active ingredient in some 70 per cent of the synthetic detergents sold for household use, the study was confined essentially to the behavior of this material during sewage treatment. Furthermore, because the presumptive evidence of adverse effects of ABS on sewage treatment processes derived from its known surface active properties, the scope of the study was limited to the active ingredient alone rather than in combination with "filler" materials used in commercial products.

Other recent experimental work has been concerned with methods for increasing the normal ability of sewage treatment processes to remove or destroy ABS. This work was based on the consideration that since detergents enter the sewer at thousands of points in the system, any removal of ABS which might become necessary in the interest of maintaining water quality must necessarily take place at the treatment plant rather than at the point of influent. The possibility of increasing the effectiveness of activated sludge through changes in process or operational procedures was therefore studied, as was that of adding intermediate or tertiary units for stripping ABS from the liquid surface.

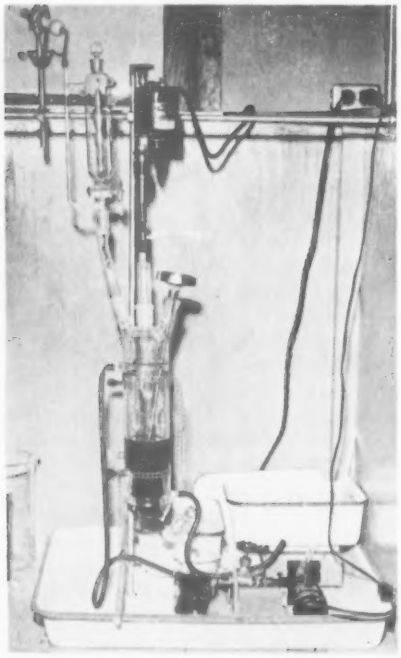

FIGURE 1.—Equipment used in sulfonating alkyl benzene.

Materials and Methods

Alkyl benzene blended from the product of five major producers was furnished by the sponsoring agency. This was converted to ABS for use in experimental work by means of the glass sulfonator shown in Figure 1. Detergent to be traced by radioassay was prepared by sulfonating small amounts of alkyl benzene with sulfur-35 in ordinary laboratory glassware.

Equipment

Several types of activated sludge units were utilized in the course of the investigation. Figure 2 shows batch units used in exploratory experiments. These consisted of 3-in. round bottom glass tubes 24 in. in height, having a capacity of 2 liters each. Compressed air was supplied through a manifold which distributed it to the several tubes through individual aquarium stones, the rate of application being regulated by simple screw clamps on rubber tubing. In Figures 3 and 4 are shown two models of laboratory scale continuous activated sludge units also utilized in the experimental work. Both made use of a cylindrical aeration chamber and a conical settling tank from which sludge was returned to the aeration chamber at a controlled rate by means of a Sigmamotor, or "finger" pump. The same pump was used to deliver the feed solution at a metered rate from a refrigerated beverage cooler having internal air circulation. Early in the investigation the unit shown

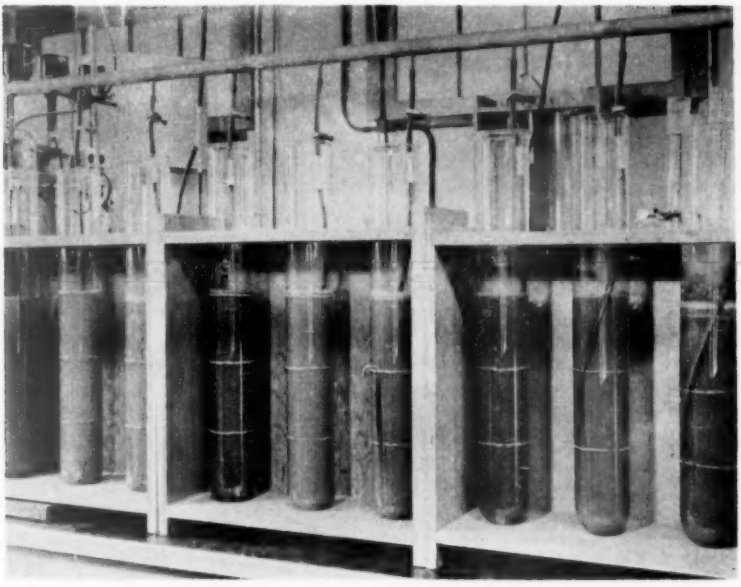

FIGURE 2.—Batch activated sludge units.

in Figure 3 was abandoned in favor of that shown in Figure 4 because of the greater ease in keeping activated sludge suspended in the smaller diameter aeration chamber with a minimum amount of air. The working capacity of each of the two units was 1.6 liters. This order of magnitude was selected on the basis of previous experience which showed such units to be equal in performance to units many times larger. The advantage of small units is that the problems of keeping feed solutions properly mixed, refrigerated, and stable are greatly reduced; and when radioactive materials are used, the cost of isotopes as well as the problems of effluent disposal are minimized.

The principal disadvantages of the small units proved to be their sensitivity to fluctuations in the strength of the feed sewage, and to the shock of withdrawing large amounts of solids necessary for analysis. Higher ABS removals and more stable operation were often obtained in experiments with 10-liter continuous units. These units are shown in Figure 5.

Both the 1.6- and 10-liter continuous units are more closely related to small centrally aerated activated sludge tanks than to the spiral flow tanks used in most activated sludge plants. Consequently it was deemed possible that they might be less effective in degrading ABS than a more typical unit in which the amount of organic food for bacteria decreases in amount as the sewage progresses toward the effluent end of the tank. To explore this possibility the multiple-cell unit shown in Figure 6 was constructed. It consisted of six 1.6-liter units in series, each with a device for introducing the effluent from the preceding tube near the cell bottom, and with an individual aeration stone. The light colored area in the lower portion of each tube in the figure is a sand filler used to reduce the tube volume to the desired value of 1.6 liters.

Figure 7 represents the equipment most used in tracing ABS[35] and its radioactive degradation products through

the activated sludge process. It consists of an Atomlab Model 21 pre-flushed flow counter, operated as a geiger counter in connection with a Tracerlab SC-51 Autoscaler. During operation the counter is continuously flushed with an inert quench gas, consisting of 99 per cent helium and 1 per cent iso-butane.

Methods

Chemical analyses of ABS were made by the procedure set forth by Moore and Kolbeson (1). It employs the principle of complexing the anionic detergent with methyl green, extracting the complex with benzene, and measuring the optical density of the benzene solution with a spectrophotometer. The method, although accurate for normal solutions of ABS in water, gives only approximate results on raw sewage or on effluent from the various units of the treatment plant. Nevertheless, it was used for lack of a more satisfactory means of determining the amount of detergent originally in the sewage.

Radiological techniques were used to trace ABS wherever possible and the principal findings of the investigation are based on tracer studies. Radioactive detergent was added in amounts appropriate to the type of counting equipment used, as determined by experiment. ABS^{35} in the liquid fraction of sewage was extracted with ether and adsorbed on bone charcoal (carbon). This was then radioassayed as a dry sample of "infinite thickness" radiologically on specially machined deep well planchets. In order to get some measure of the degree of breakdown of ABS by any process, the amount reducible to $BaS^{35}O_4$ by a bromine water oxidation was determined by counting the activity of the dried residue in deep well planchets. Residual S^{35} activity in liquids, representing the amount of intermediate products of ABS degradation, was determined by direct plating techniques. Unfortunately, a loss of S^{35} occurred in this process, presumably by volatilizing some of the intermediate decomposi-

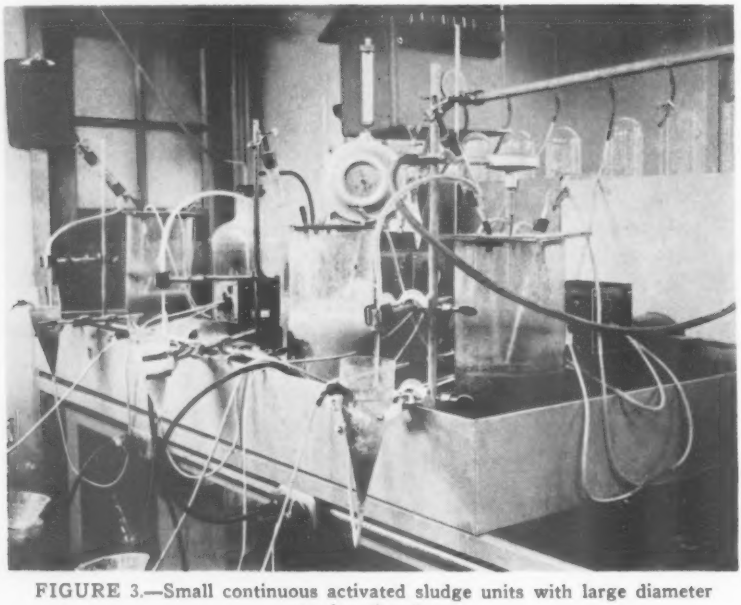

FIGURE 3.—Small continuous activated sludge units with large diameter aeration chambers.

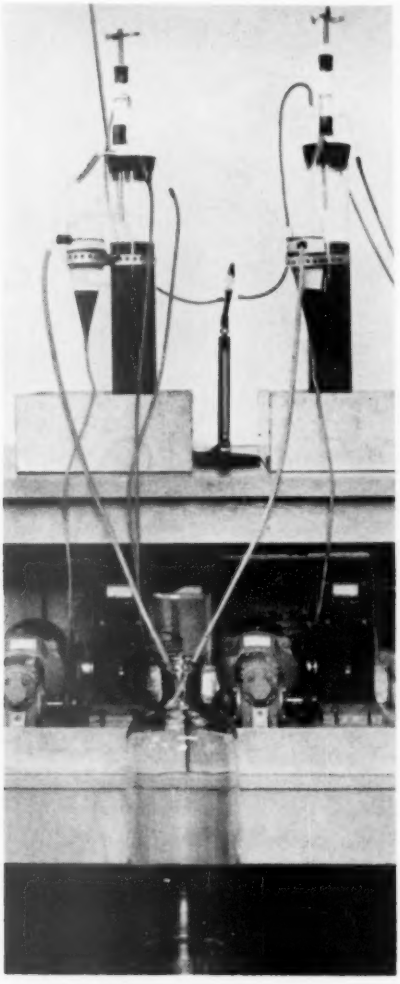

FIGURE 4.—Continuous activated sludge unit of 1.6-liter capacity.

tion products. A radioactivity balance was impossible; therefore, it was necessary to depend on statistical measures of reliability for interpretation of the accuracy of analytical results.

ABS^{35} adsorbed on solids was removed by an alcohol and ether extraction and counted on carbon. Residual radioactivity on the solids was counted in deep well planchets containing the dried sample mixed with celite. By establishing a common geometry between carbon and the various other solids assayed the results were reducible to a comparable basis.

Various substrates were used for feeding activated sludge systems. Synthetic sewage, however, was abandoned early in favor of settled domestic sewage. Whenever constant BOD was considered important, this settled sewage was bot-

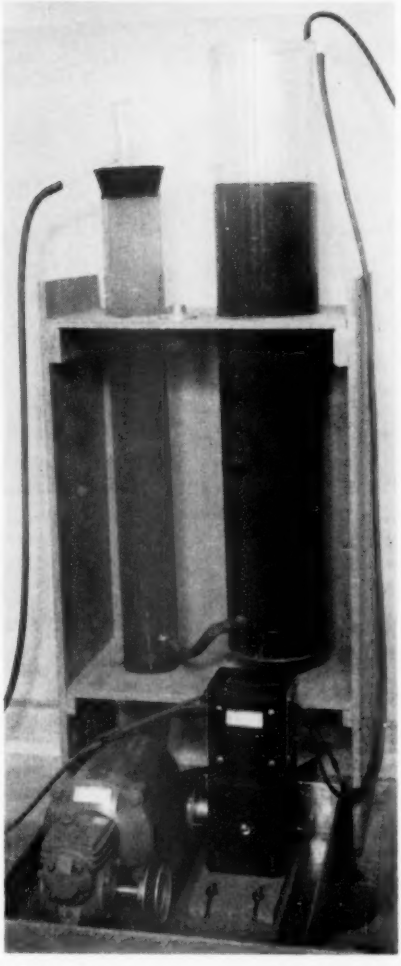

FIGURE 5.—Continuous activated sludge unit of 10-liter capacity.

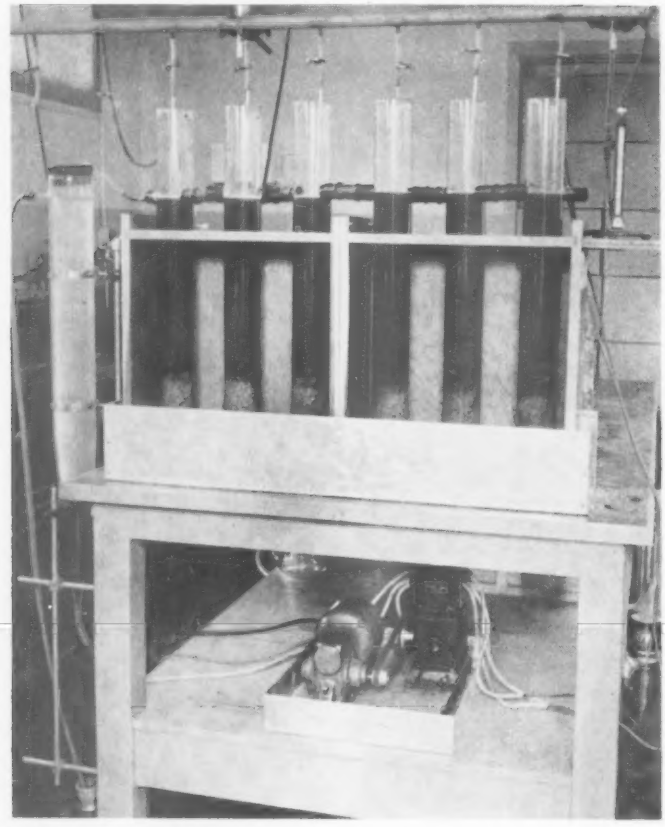

FIGURE 6.—Multiple compartment continuous activated sludge unit of 9-liter capacity.

tled and sterilized in quantities sufficient to meet the needs of an entire experiment.

Removal of ABS by Sedimentation

Inasmuch as the initial step in sewage treatment is the separation of solids from liquids, determinations were made of the amount of ABS removed from sewage by primary sedimentation. It had been variously reported in the literature, on the basis of colorimetric analyses, that 30 per cent or more of the detergent in raw sewage is adsorbed on the solids which settle out within a 2-hr detention period. Determinations made by the methyl green method of analysis supported this observation, but a vast error inherent in the method was later revealed by radioassay.

Preliminary Studies

Preliminary studies were made on the amount of ABS adsorbed by various types of solids, including those which might be associated with sewage; and of the effect of solids concentration and ABS concentration on the percentage adsorbed. In the first of these, one-liter suspensions of each of the several materials shown in Table I were made up. No attempt was made to alter the

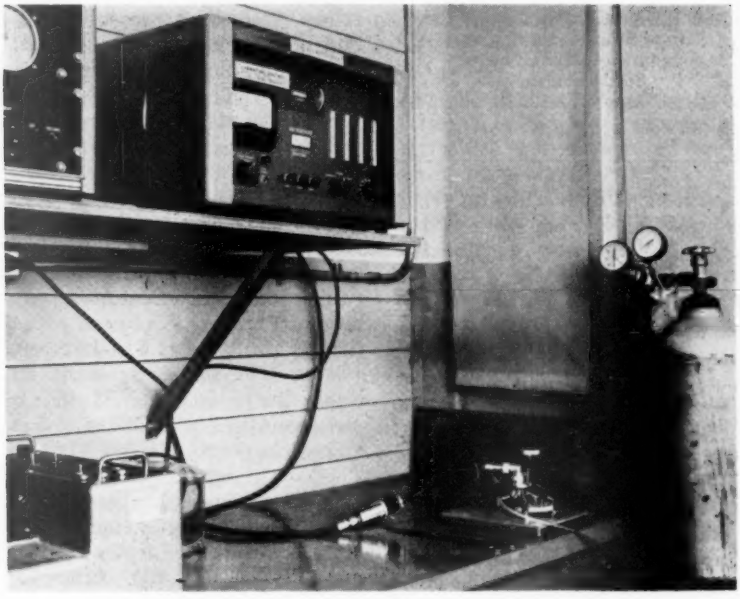

FIGURE 7.—Radiological counting equipment.

solids concentration in raw or previously settled sewage but other suspensions were of the order of 500 mg/l. After a period of mixing with equal amounts of ABS^{35}, all suspensions were allowed to settle for one hour prior to withdrawing samples of the supernatant for radioassay.

The results show that only a small amount of ABS was adsorbed on any of the solids tested, with the exception of activated sludge. However, any effect the difference in solids concentration in raw sewage and activated sludge might have had is not apparent in Table I, hence it remained for later observations, some of which are herein reported, to prove the data valid.

TABLE I.—Amount of ABS^{35} Adsorbed on Various Solids and Removed by One Hour of Sedimentation

Material Observed	Solids Concentration (mg/l)	ABS Removed by Settling 1 hr (per cent)
Distilled water	0	0
Raw sewage	85	3
Settled sewage*	40	2
Activated sludge	580	19
Sand	500	0
Silt	500	0
Bentonite	500	3
Kaolinite	500	2.5
Diatomaceous earth	500	3

* Previously settled for two hours.

Solids Concentration Effects

The possible effect of solids concentration on the percentage of ABS adsorbed and removed with solids was explored in an experiment summarized in Table II. Solids were concentrated by evaporation of raw sewage on a steam bath; homogenization in a blender; then resuspension in distilled water in the concentrations shown in the table. Suspensions were shaken periodically during a 24-hr period of contact with ABS^{35}, and finally allowed to settle for 24 hr.

The observed percentages of removal show that although removal in-

TABLE II.—Relationship Between Raw Sewage Solids Concentration and ABS[35] Removal by Sedimentation

Solids Concentration (ppm)	Removal of ABS (per cent)
0	0
500	6.6
1,000	8.7
1,500	10.2
2,000	13.8

creases with solids concentration, it follows a typical die-away curve. Furthermore, the highest rate of adsorption occurs in the range of from 0 to 500 mg/l settleable solids—the range most typical of domestic sewage. The value of 6.6 per cent in 24 hr sedimentation (Table II) as compared to 3 per cent in 1 hr (Table I), therefore, confirms the previous conclusions that type of material rather than difference in solids concentration accounts in large measure for the differences in adsorption reported in Table I.

ABS Concentration Effects

In order to determine the effect of fluctuations in ABS concentration in sewage on its removal by sedimentation, this factor was explored in a preliminary fashion by the experiment summarized in Table III. Various amounts of ABS[35] were added to raw sewage having a very high solids concentration. After a 4-hr contact period all samples were filtered through celite and analyses were made of both filtrate and solids. Radioassay was used on solids and colorimetry on the filtrate.

Assuming the relationship previously shown in Table II to be valid, the 14.5-per cent removal value at 2,690 mg/l solids, shown in Table III would seem to be in line with the value of 13.8 per cent at 2,000 ppm shown in Table II, since some increase might result both from the greater solids concentration and from the fact that filtration should remove more solids than 24-hr sedimentation. Pursuing this line of reasoning, the increase from 14.5 to 18.4 per cent (Table III) would represent an increase due to the combined effect of increasing ABS (from 22.0 to 34.5 mg/l) and solids (from 2,690 to 3,720 mg/l). Thus, only changes in the last four values in Table III, where solids concentration is relatively constant, can be taken as reflecting the effect of increasing ABS concentration. When successive increments of ABS concentration in the table are compared with the corresponding changes in ABS adsorbed on solids, and when it is considered that the ABS concentrations are several times those encountered in domestic sewage and that filterable rather than 2-hr settleable solids are involved, it seems evident that changes in concentration play an insignificant role in determining the amount of ABS removed by sedimentation in a sewage treatment plant.

TABLE III.—Relation of ABS Concentration to Its Adsorption on Suspended Solids

Material Tested	ABS* (mg/l)	Solids (mg/l)	ABS on Solids (per cent)
Raw sewage + 1 ml ABS[35]	22.0	2,690	14.5
Raw sewage + 2 ml ABS[35]	34.5	3,720	18.4
Raw sewage + 3 ml ABS[35]	39.0	3,650	22.8
Raw sewage + 4 ml ABS[35]	56.5	3,480	22.6
Raw sewage + 5 ml ABS[35]	65.5	3,840	26.7

* Determined colorimetrically.

Adsorption Tests

The total amount of ABS adsorbed on suspended solids, and the fraction

TABLE IV.—Adsorption of ABS[35] on Raw Sewage Solids, and Amount Removed by Sedimentation

Material Observed	ABS Removed (per cent)			
	Test No. 1	Test No. 2	Test No. 3	Avg
Raw sewage	0	0	0	0
Settled sewage (2 hr)	3.6	3.3	2.5	3.1
Filtered sewage	12.1	10.5	—	11.3

removed by a 2-hr settling period, were determined in a number of experiments. The results of three of these are reported in Table IV. In each case ABS[35] was mixed with raw domestic sewage for one hour to insure complete contact and to establish an equilibrium between added ABS[35] and normal ABS already in the sewage. Samples for radioassay were then taken before and after a 2-hr settling period, and again after the suspended solids had been removed by filtration.

The results show that only about 3 per cent of the ABS was removed by sedimentation. Later work indicated that a value of 2 per cent might be more typical. A little more than one-third of the ABS adsorbed on filterable solids appeared on settleable solids (2 hr), and only about 11 per cent of the total ABS was on the total suspended solids.

In the course of the investigation herein reported various experiments with sedimentation were performed. In the absence of detergent-free domestic sewage, practical comparisons were possible only between the normal detergent-carrying sewage in local sewers and the same material after various amounts of ABS were added, or between the behavior of such sewage in sedimentation experiments and the average performance of sedimentation tanks reported throughout the past. Results of such comparisons permit the following statements:

1. The amount of ABS present in raw domestic sewage is probably of the order of 5 to 10 mg/l, although in the absence of better methods of analysis the actual concentration is only approximated by colorimetric tests.

2. Reports of 30 per cent or greater removal of ABS by sedimentation are based on methods of analysis which are shown to be grossly inaccurate.

3. Although some 10 to 12 per cent of the ABS in sewage may be associated with the solids, the maximum removal which is likely to occur in normal primary sedimentation tanks is of the order of 2 to 4 per cent.

4. In view of the small amount of detergent taken out with settleable raw solids, secondary sewage treatment processes must be relied on to remove important amounts of detergent.

5. No interference with normal sedimentation was observed in the experiments, and in view of the relatively small amount of ABS on solids at present levels of detergent concentration in sewage it is unlikely that such interference is an important factor in the behavior of primary settling tanks.

6. The concentration of ABS which might reach the digester with fresh sewage solids in a 95-per cent sludge would be many times that in the original raw sewage. Studies of the fate of this material during sludge digestion have not yet been undertaken.

Degradation of ABS by Activated Sludge

Having demonstrated that primary sedimentation is of little significance in the removal of ABS by sewage treatment, attention was turned to the effect of secondary processes. Because activated sludge is the most widely used secondary treatment process in large installations, and because foaming of aeration tanks has been reported to result from detergents, the ability of activated sludge to break down ABS, and the factors affecting that ability, became the principal concern of the investigation. Among the variables studied were BOD of sewage, activated sludge solids concentration, and period and rate of aeration.

Batch Tests

Initial tests were designed to learn whether ABS is susceptible to biological degradation. The disappearance of ABS as a function of time was observed in a sewage-fed batch unit over an aeration period of 48 hr. Results showed a 70-per cent removal, with half of this occurring in the first 4 hr. In

TABLE V.—Results of Operating Continuous Activated Sludge Units on Synthetic Substrate Containing ABS

Days	ABS in Feed (mg/l)	Reduction in ABS (per cent)		Reduction in BOD (per cent)		Activated Sludge Solids Conc. (mg/l)		(SO_4) As $BaS^{35}O_4$ (cpm)		
								Infl.	Effluent	
		Unit I	Unit II	Unit I	Unit II	Unit I	Unit II		Unit I	Unit II
1	5.4	68.1	60.6	99	97	2,670	3,042	36	29	32
2	6.0	25.0	20.3	96	97	3,160	3,092	40	24	32
3	6.0	21.9	28.7	95	96	3,312	3,796	29	30	27
4*	—	—	—	—	—	—	—	—	—	—
5*	—	—	—	—	—	—	—	—	—	—
6	6.0	65.5	62.8	91	96	2,298	3,096	22	17	20
7	5.6	29.5	23.5	89	96	3,172	2,618	22	32	27
8	6.0	19.1	17.6	93	93	3,222	2,624	25	—	34
9	5.6	19.5	21.1	91	94	3,472	3,502	29	41	26

* Wasted solids on these days.

spite of the limitations of the colorimetric method used, it was made clearly apparent that bio-degradation of ABS is possible. Further experiments were then carried out with a synthetic sewage in which the ingredients entering the system could be controlled. After a period of acclimation, during which time several units were fed amounts of ABS varying from 2 to 10 mg/l, influent and effluent samples were analyzed colorimetrically. For this range of detergent concentration no significant variation in ABS removal was found, all tubes showing about 40 per cent removal within 4 hr.

Normal and Synthetic Sewages

Continuous activated sludge systems were then set up and fed synthetic sewage carrying 6 mg/l of added ABS with tracer amounts of ABS^{35}. In these systems an average removal of 25 per cent of the ABS was achieved over a test period of nine days. When domestic sewage was substituted for the syn-

TABLE VI.—Results of Operating Activated Sludge Unit on Settled Domestic Sewage

Days	ABS in Sewage Feed (mg/l)	Reduction in ABS (per cent)		Reduction in BOD (per cent)	Sludge Conc. (mg/l)	$BaS^{35}O_4$ (cpm)	
		Radio-assay	Colorimetry			Influent	Effluent
1	2.25	75.9	57.6	66	—	12	30
4	3.8	48.6	47.4	87	—	32	62
6	3.8	54.3	50.0	95	1,834	12	55
7	4.0	54.2	60.0	91	1,958	8	62
8	2.2	57.6	23.7	93	—	13	57
11	3.8	68.4	13.1	91	2,384	23	78
13	3.9	58.7	28.2	—	1,798	—	58
14	2.6	47.6	23.0	83	1,746	15	58
18	4.0	37.7	20.0	56	1,472	8	80
19	9.0	48.0	70.0	85	—	6	78
20	—	56.3	—	85	—	18	99
21	8.0	52.3	60.0	—	—	6	83
25	4.0	46.2	22.5	96	—	10	71
26	3.6	54.6	44.5	90	—	8	85
27	4.6	57.6	44.5	74	—	11	104
28	—	60.4	—	92	—	6	40

thetic substrate, however, removals over a 28-day period averaged 54 per cent. Results of these two studies are summarized in Tables V and VI.

From a study of Tables V and VI several important facts are evident:

1. In terms of BOD removal, both systems functioned well as sewage treatment units.
2. Synthetic sewage-fed sludges were markedly less interested in ABS as a substrate than were the sludges fed on normal sewage.
3. As shown by the increase in radioactivity as $BaS^{35}O_4$ through the systems, the amount of ABS broken down to inorganic sulfate was appreciable in the domestic sewage-fed units, and essentially none in the synthetic-fed units.
4. Colorimetry (methyl green method), while sometimes producing results of reasonable accuracy, is affected in an unpredictable manner by domestic sewage, hence of limited value as a research tool.
5. ABS removal on the first day after the introduction of ABS as ABS^{35} appears much higher than on subsequent days.

Confirmation of the foregoing conclusions came from a number of similar experiments, consequently the use of synthetic substrate was abandoned for all but a few special studies. The last conclusion, however, led to further studies.

Solids Wasting

The decline in ABS^{35} removal between the first and second day (some 27 per cent in Table VI) was repeatedly observed as having a value of 20 per cent or greater. This phenomenon seemed readily explainable in terms of equilibrium adsorption of ABS on solids, hence it was considered possible that a regular wastage of solids up to the regenerative capacity of the sludge might, by keeping this equilibrium unperience, suggested the possibility that satisfied, lead to a higher removal of ABS. Experiments were carried out at activated sludge solids concentrations ranging from 1,200 to 2,000 mg/l with wastage up to 20 per cent of the solids in the system once each day. This level of wastage proved detrimental to the health of the system. Ten per cent, however, was easily tolerated but no increase in ABS removal resulted.

Solids Concentration Effects

To determine the effect of solids concentration on the ability of an activated sludge to degrade ABS, the 10-liter capacity continuous unit was operated for 120 consecutive days. Some of the results are shown in Table VII.

During the first 70 days the solids level averaged 1,432 mg/l, while the average for the subsequent 38- and 12-day periods was 2,038 and 3,696 mg/l, respectively. The 2,038-mg/l concentration represented the maximum which the low BOD sewage in the local sewers at that time would support. At the lower solids concentration it was found that the activated sludge produced an average ABS degradation of 39.4 per cent, in comparison with 51.6 per cent at the higher concentration. During the final 12 days of the experiment settled sewage from another city and having a BOD of 150 ppm was batch-sterilized and used as a substrate. The resulting solids concentration averaged 3,696 mg/l, producing an ABS removal of 54.1 per cent.

The results of a later experiment designed to explore further the effects of solids concentration are summarized in Table VIII. During the first 10 days of the experiment no solids were withdrawn from the system. ABS removals began at the unusually high value of 71 per cent and remained high for several days. From the 6th day onward, however, a progressive decline set in until the removal on the 10th day was but 19.3 per cent. Previous ex- ABS reduction remains high only as long as the solids concentration is gen-

TABLE VII.—ABS and BOD Reduction at Various Solids Concentrations in Activated Sludge Mixed Liquor

No. of Days	Solids Concentration in Mixed Liquor (mg/l)	Per Cent Influent S^{35} in Effluent			ABS Reduction (per cent)	BOD Reduction (per cent)
		As ABS	As $S^{35}O_4$	As Intermediate Products of Degradation		
70	1,432	59.4	6.0	33.4	39.4	88
38	2,038	48.4	8.2	43.4	51.6	94
12	3,696	45.9	10.6	43.5	54.1	97

erally increasing, and falls off when the concentration becomes essentially constant, regardless of the amount of solids present. To explore this possibility, daily mass withdrawals of sludge were begun. From the 13th to the 20th day the increase in ABS reduction tended to parallel that of the sludge concentration and thus seemed to support the postulate that an increasing sludge concentration is conducive to higher degradation. Again during the final days a generally slow increase in sludge concentration was accompanied by a high ABS removal, in excess of 60 per cent.

Throughout the experiment the efficiency of the system in terms of BOD reduction remained consistently high, evidently insensitive to the factors affecting ABS removal. However, when the results were considered in the light of previous observation it was concluded that the efficiency of ABS degradation is not a function of solids fluctuations as minor as those reported in Table VIII but is influenced by some critical factors which are not reflected in any of the analytical tests normally used in the operational control of activated sludge plants.

It was concluded, however, that in general greater ABS reduction occurs at high solids concentrations than at low; and that solids concentrations of the order of 5,000 to 6,000 mg/l accompany degradation of 60 to 70 per cent of the influent ABS. While the methods for insuring uniform high ABS

TABLE VIII.—Reduction in ABS^{35} and BOD in High-Solids Activated Sludge Unit

Days After Start of Experiment	Solids Concentration (mg/l)	Solids Wasted		Reduction ABS (per cent)			BOD Reduction (per cent)
		Mg/l	Per Cent	Over-all	Waste Solids	Net	
1	4,952	0	0	71.3	0	71.3	—
2	5,604	0	0	60.1	0	60.1	91.9
3	5,548	0	0	77.2	0	77.2	96.3
6	5,976	0	0	52.8	0	52.8	96.4
7	6,304	0	0	47.5	0	47.5	96.4
8	5,636	0	0	26.1	0	26.1	94.8
9	5,912	0	0	17.8	0	17.8	92.5
10	6,400	0	0	19.3	0	19.3	92.8
13	6,736	592	8.8	34.6	1.0	33.8	97.3
14	6,100	512	8.4	40.3	1.0	39.3	96.5
15	5,724	612	10.7	39.4	1.2	38.2	94.4
16	5,804	536	9.2	45.8	1.1	44.7	89.8
17	6,196	420	6.8	51.3	0.7	50.6	97.2
20	6,240	1,950	31.3	60.9	3.6	57.3	90.8
21	4,792	0	0	67.6	0	67.6	85.3
22	5,132	0	0	62.7	0	62.7	86.5
23	5,032	0	0	64.6	0	64.6	85.2
24	5,404	0	0	61.8	0	61.8	89.9

removal by activated sludge have not yet been established, operation at greater than usual solids concentration is one method of obtaining maximum removal of ABS without modification of existing activated sludge plants. Furthermore, additional experience supports the previous conclusion that a normal activated sludge system itself can remove about half of the influent ABS. Since sedimentation is relatively ineffective, it might be said that some 50 per cent of the ABS in raw sewage may be removed by an ordinary sewage treatment plant having activated sludge as the secondary treatment process.

Aeration Rate and Detention

The effects of aeration rate and period of aeration were studied in limited detail. As previously noted, about half of the ABS degradation in a 48-hr aeration period was accomplished in the first 4 hr. Consequently most of the investigative work was done at the 4- to 6-hr aeration periods typical of sewage treatment plants.

Aeration rate per se showed no evidence of being an important factor in ABS degradation. The minimum rate of aeration required to keep activated sludge in suspension was the controlling factor. In some of the first aeration units constructed the aeration rate necessary to accomplish this broke up the solids to such a degree that they did not settle out in the settling tank and hence were carried over into the effluent. Minimum aeration rates therefore proved important largely for physical reasons.

In the course of operation of many experimental activated sludge systems no evidence appeared to suggest that the amount (5 to 10 mg/l) of ABS likely to be present in domestic sewage has any toxic effects on activated sludge. Increasing the ABS dosage from the normal range to 50 mg/l reduced by half the solids concentration in activated sludge mixed liquor. The first effects were observable in the 20 to 25 mg/l range in terms of per cent of ABS degraded as follows:

ABS (mg/l)	Per Cent Degraded
4.4	54
12.0	52
22.0	44

TABLE IX.—Average Distribution of S^{35} in Liquid Effluent from Activated Sludge Aeration Tank

Experiment	No. of Tests	Unaltered ABS^{35} (avg per cent)	Intermediate Products of Degradation* (avg per cent)	Final Product of ($S^{35}O_4$) Degradation (avg per cent)
A	10	61.1	52.6	6.3
B	18	53.1	40.6	6.3
C	16	59.4	35.5	5.1
D	18	47.3	43.9	9.2
Weighted average	—	54.6	39.6	6.8

* Includes any experimental error since approximately one-half of values shown represent radioactivity (S^{35}) not recoverable by present radiological techniques.

ABS Distribution

The distribution of ABS^{35} and its degradation products in the liquid and solid fractions of activated sludge as observed in a number of experiments is summarized in Tables IX and X. The percentages in Table IX refer to total influent ABS to the activated sludge tank. This represents 96 to 98 per cent of the ABS entering the treatment plant. Since an equilibrium

TABLE X.—Average Distribution of S^{35} in Activated Sludge Solids

Experiment	No. of Tests	Unaltered ABS^{35} (avg per cent)	Intermediate Products of Degradation (avg per cent)	Final Product of Degradation ($S^{35}O_4$) (avg per cent)
A	10	76.1	18.6	5.3
B	14	86.3	10.4	3.3
C	16	83.7	12.6	3.7
Weighted average	—	82.7	13.3	4.0

builds up on solids very quickly and since essentially no solids leave the system, the table summarizes the fate of ABS during activated sludge treatment.

The percentages in Table X are based on the total ABS[35] associated with the solids either as unaltered ABS or as degradation products under equilibrium conditions.

From Table IX it may be seen that of the ABS entering the activated sludge tank 54.6 per cent appeared in the effluent as ABS, 39.6 per cent as unidentified intermediate products of bio-degradation, and 6.8 per cent as final products of degradation (assuming the bromine water oxidation used does not itself add to the sulfates produced biochemically). In a hypothetical case based on 3 per cent removal of the ABS in the primary settling tank, the fate of this ABS might then be somewhat as follows:

ABS Status	Per Cent
Removed by sedimentation	3
In plant effluent	53
As intermediate degradation products	37.4
As final degradation products	6.6
Total	100

As shown in Table X, of the ABS more or less constantly associated with the solids, which might therefore be considered as recycled to new cells as old cells disintegrated, 82.7 per cent represents ABS, 13.3 per cent is in intermediate products of ABS degradation, and 4 per cent is inorganic sulfates.

Modifications of Normal Activated Sludge Process

Two-Stage System

A number of experiments were run for the purpose of exploring simple process or plant modifications as a possible means of attaining removals of ABS greater than the 50 to 70 per cent previously achieved. The first of these was a simple multiple-stage system comprising two units of the type previously noted in Figure 4 arranged as illustrated in the flow diagram, Figure 8. The system was operated on a 4-hr aeration period in each stage, with return sludge concentrated to 50 per cent volume.

The results of an 11-day period, following a period for equilibrating the system, are summarized in Table XI.

It is notable from Table XI that whereas the influent BOD to the first stage averaged 124 mg/l, only 5.6 mg/l went into the second-stage aeration. Nevertheless, the activated sludge in the second-stage was quite healthy. The 2 mg/l BOD reduction which it was able to achieve was not quite sufficient to sustain the unit, therefore solids from the primary unit were added whenever the solids concentration fell below 1,200 mg/l. As shown in the table this was done on the first and fourth days only, but would have been necessary again on the 11th day had the experiment been continued.

In view of the shortage of substrate and the apparent health of the acti-

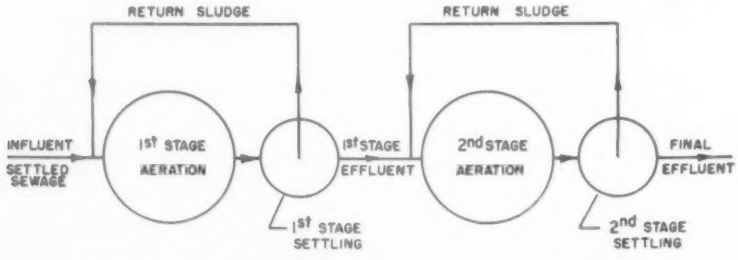

FIGURE 8.—Flow diagram for two-stage activated sludge system.

TABLE XI.—Reduction in ABS and BOD by Two-Stage Activated Sludge Unit

Days	ABS Reduct. (per cent)		BOD (mg/l)			BOD Reduct. (per cent)		$S^{35}O_4$ (mg/l)		Solids Conc. (mg/l)	
	1st Stage	Over-all*	In-fluent	1st Stage Effl.	Final Effl.*	1st Stage	Final*	1st Stage Effl.	Final Effl.*	1st Stage	2nd Stage
1	53.9	56.8	133	4	3	97.0	97.7	55	66	3,292	1,092†
2	44.0	43.5	136	5	3	96.3	97.8	61	75	2,976	1,316
3	61.0	59.9	128	6	3	95.3	97.7	74	86	3,228	1,252
4	52.0	50.8	128	5	3	96.1	97.7	85	106	3,572	1,168†
7	54.9	58.4	119	6	3	95.0	97.5	68	98	3,820	1,604
8	53.9	55.9	110	6	5	94.5	95.5	73	99	4,036	1,540
9	59.7	60.3	118	6	4	94.9	96.6	87	109	3,632	1,368
10	58.4	56.0	119	7	5	94.1	95.8	74	105	3,780	1,212
11	61.7	62.2	—	—	—	—	—	87	116	4,724	866
Avg	55.5	56.0	124	5.6	3.6	95.4	97.0	74	96	3,673	1,269
C_v	5.2	5.4	—	—	—	—	—	10.7	15.7	—	—

* First plus second stage.
† Solids added from first-stage.

vated sludge it would not have been surprising had ABS been more vigorously attacked. However, the ABS reduction accomplished by the second-stage amounted to only about 1 per cent of the ABS reaching the system, and added but 0.5 per cent to the 55.5 per cent ABS reduction accomplished by the first-stage. In contrast, the second-stage removed 36 per cent of the BOD reaching it, but because of the very high BOD reduction in the primary stage this added but 1.6 per cent to the over-all BOD reduction.

The limited degradation of ABS by the second-stage is evidence that the less readily available organic matter represented in the 5-day BOD may lack some essential factor necessary for organisms to attack ABS.

While the activated sludge in the second unit showed little interest in ABS as a substrate, an impressive increase in the $S^{35}O_4$ in the final effluent over that in the first-stage effluent indicates that such was not the case with the intermediate products of ABS degradation. Data in Table XI show that this increase amounted to 30 per cent, proving conclusively that intermediate products from the primary unit were serving as substrate in the secondary.

Several previous experiments indicated a tendency for ABS reduction by activated sludge to vary inversely with BOD in the influent sewage. All of these involved ordinary weak domestic sewage as contrasted with a sewage impoverished by the removal of the most readily available organic matter, as in the second-stage of the system reported in Table XI. This conflicting and inconclusive evidence led to two additional studies designed to explore the relationship of ABS and BOD reduction.

ABS-BOD Ratio Variation

In the first of these, both the initial ABS-BOD ratio and the degree of availability of organic matter involved in the 5-day BOD of a sterilized settled sewage were altered. A two-stage system, illustrated by the flow diagram in Figure 9, was set up and operated during an 11-day test period after an initial equilibrium had been achieved.

The influent settled sewage was first introduced into a 1-hr aeration tank where it came in contact with normal

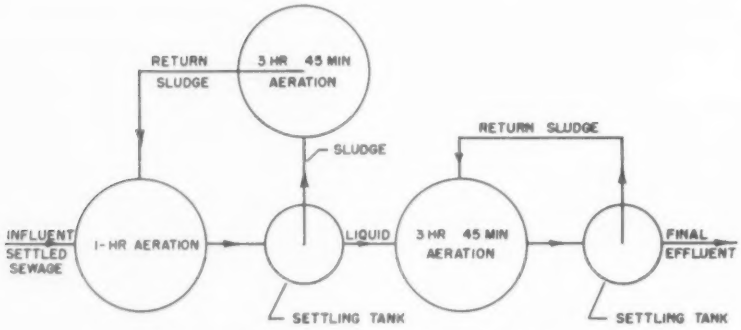

FIGURE 9.—Flow diagram for high BOD-low BOD system.

activated sludge. Here a rapid adsorption of BOD occurred (average 86 per cent) as shown in Table XII. Inasmuch as one hour is insufficient time for activated sludge to metabolize the adsorbed BOD-exerting organic matter, the sludge was settled out and fed into a larger unit having an aeration period of 3 hr and 45 min. Here the biological activity was stabilized and the mixed liquor overflow was recirculated back to the smaller unit. The effluent from the settling tank, carrying an average of 14 per cent of the influent BOD and 64.2 per cent of the influent ABS, was then treated in its own special activated sludge unit as illustrated in Figure 9.

Although the secondary unit maintained a thriving activated sludge on its low (13 mg/l) BOD, and removed 73 per cent of the BOD entering it, only 14 per cent of the ABS reaching the unit was degraded. This added but 9 per cent to the removal of the original influent ABS, thereby bringing the average over-all reduction in ABS to 44.8 per cent. Since such a value is readily attained by a single unit with 4-hr aeration, it was concluded that the system had no particular merit.

From the data in Table XII it is evident that in both the first and final

TABLE XII.—Reduction in ABS and BOD by Special High BOD-Low BOD Activated Sludge System

Days	ABS Reduct. (per cent)		BOD (mg/l)			BOD Reduct. (per cent)	
	1st Stage	Over-all*	Influent	1st Stage Effl.	Final Effl.*	1st Stage	1st + Final Stage
1	39.7	63.5	165	13	5	—	97
2	43.0	53.3	78	11	4	86	95
3	39.9	49.9	101	10	3	90	97
7	39.2	42.5	125	14	3	82	95
8	37.5	43.1	117	14	3	88	97
9	33.2	40.8	74	13	4	85	97
10	26.9	34.9	108	16	3	86	97
11	28.5	33.2	108	15	3	80	97
Average	35.8	44.8	111	13	3.5	86	97
C_v	5.3	9.4	—	—	—	3.2	1.0

* First plus final stage.

stages there was a tendency for the ABS reduction to decrease with time. This is not considered to be evidence of any approaching failure of the type of system used because in previous investigative work covering periods up to 120 days of continuous operation, the effectiveness of an activated sludge unit in removing ABS was observed to increase and decrease without a correspondingly profound change in BOD reduction, and without any obvious reason. Presumably a period of increase would have followed and may have led to a somewhat higher over-all average reduction in ABS. There was, however, no indication that the system would produce results sufficiently greater than conventional aeration to justify its adoption, hence the experiment was terminated after 11 days.

Failure of the system to accomplish impressive levels of ABS degradation did not, however, prove the original observation of low influent BOD-high ABS removal to be erroneous since the organic material representing BOD entering the second unit may well have been less readily available than that adsorbed by the activated sludge in the first stage. It did, however, eliminate one possible practical way of achieving a reduction in BOD concentration without the corresponding reduction in ABS concentration which would result from a simple dilution of the influent sewage. Thus, the system was incapable of taking advantage of any possible increase in ABS degradation which might accompany lowered influent BOD.

Recirculation Tests

A second series of experiments was designed on the assumption that if some 50 per cent of ABS in fresh sewage can be degraded by activated sludge, some similar amount of the remainder should likewise be attacked if the sewage could be freshened again and subjected to activated sludge treatment a second time. If such a process proved effective it was proposed to add blended raw sewage solids from the primary sedimentation tank to the effluent of a first-stage aeration system, thereby restoring readily putrescible solids without any important increase in ABS, because of its low adsorption on raw sewage solids. This reinforced effluent might then be fed to a second aeration tank with the expectation that a further important degree of ABS degradation should accompany the disappearance of much of the added BOD unless, of course, the soluble products of the bio-stabilization of organic matter in the first-stage should be inhibitory, or the organic matter comprising the BOD of the settled solids should be greatly unavailable in comparison with that dissolved in the sewage entering the first stage.

Using an activated sludge system such as previously shown in Figure 8, consisting of two 1.6-liter aeration units with 4-hr aeration and a return sludge concentration of 50 per cent, three experimental runs were carried out. In all experiments a solids concentration in the 5,000 to 6,000 mg/l range was maintained in the first-stage mixed liquor in order to encourage the maximum possible ABS reduction.

In the first study, effluent from the primary unit was reinforced with a synthetic substrate prepared in accordance with Weinberger (2), except that the usual castile soap and diatomaceous earth were omitted as ingredients. The principal results of this study are summarized in Table XIII.

Raw Sewage Solids Additions

A preliminary 5-day experiment, summarized in Table XIV, was carried out utilizing raw sewage solids to increase the BOD of the second-stage influent. The procedure was to collect and refrigerate the first-stage effluent over a period of 24 hr; then add raw

TABLE XIII.—Reduction in ABS and BOD by Two-Stage Activated Sludge System with Added BOD from Synthetic Substrate

Days	ABS Reduction* (per cent)			Infl. BOD (mg/l)		BOD Reduct. (per cent)		Solids Conc. (mg/l)	
	1st Stage	2nd Stage	Over-all	1st Stage	2nd Stage	1st Stage	2nd Stage	1st Stage	2nd Stage
1	39.2	39.0	62.9	173	97	96.5	83.5	6,596	3,316
2	32.2	4.3	35.1	186	129	97.8	88.4	6,224	3,328
3	31.9	7.5	37.0	227	246	79.3	94.3	6,428	3,172
4	39.9	16.4	49.7	269	250	96.7	—	5,736	3,500
5	—	—	—	—	—	—	—	5,984†	3,020
7	36.5	32.0	56.8	182	232	88.5	94.4	5,208	4,160
8	34.1	17.6	45.7	191	147	97.4	94.6	6,392†	4,456
9	37.5	18.5	49.1	182	155	91.2	87.7	4,192	3,956
10	39.2	17.3	49.7	188	135	97.9	94.8	4,974	3,922†
11	40.7	29.0	57.9	180	129	98.3	—	5,056	3,432
14	38.1	10.1	44.3	145	141	89.7	—	5,160	3,496
15	28.5	50.7	64.7	166	317	90.4	95.0	5,404	4,176
21	52.8	15.2	60.0	195	175	97.9	90.9	6,104	3,704
22	51.1	0.0	51.1	231	192	96.1	95.3	6,572†	3,904
23	53.7	13.4	59.9	224	181	98.7	94.5	5,640	4,092†
24	57.0	21.0	66.0	167	116	98.8	90.5	5,628	3,392
25	50.9	25.3	60.3	217	104	95.4	—	6,140	3,364
Average	40.0‡	19.6‡	51.4‡	195	172	94.4	92.4	5,732§	3,670§

* Percentage of own influent.
† Solids wasted.
‡ Considering corrections for solids wasted of 1.5, 0.2, and 1.7 per cent, respectively.
§ Per cent volatile, 81.5 and 75.5, respectively.

sewage solids which had been thoroughly dispersed in a blender, and feed the mixture to the second-stage over a 24-hr period.

From the data shown in Table XIV it was concluded that insufficient BOD had been restored to the sewage, hence a more extensive experiment was conducted, utilizing a greater amount of raw sewage solids. The results of this experiment are summarized in Table XV.

An examination of Tables XIII, XIV, and XV reveals a number of important facts.

1. In no case did the first stage accomplish the degree of ABS removal of which such systems are known to be capable on the basis of numerous previous experiments. For example, the activated sludge system reported in Table XI shows an 11-day average reduction of 55.5 per cent by a first-stage unit which in all observable respects was similar to the first-stage used in the three experiments summarized in Tables XIII, XIV, and XV, except that its lower solids concentration in the mixed liquor should cause it to be less efficient. Further, comparisons with the results reported in Table X show again the unpredictable nature of activated sludge in degrading ABS.

2. The second-stage likewise removed a small but significant amount of influent ABS (20 to 25 per cent). Apparently the nature of the organic matter exerting the BOD was not involved since the readily available synthetic sewage led to no better efficiency than did raw sewage solids.

3. As in previous experiments, the efficiency of the units for sewage treatment, as measured by BOD reduction, was consistently high.

TABLE XIV.—Reduction in ABS by Two-Stage Activated Sludge System with Added BOD from Raw Sewage Solids

Days	ABS Reduction (per cent)			Infl. BOD (mg/l)		BOD Reduction (per cent)		Solids Conc. (mg/l)	
	1st Stage	2nd Stage*	Over-all	1st Stage	2nd Stage	1st Stage	2nd Stage	1st Stage	2nd Stage
1	35.8	43.3	63.6	147	64	98	—	5,184	4,608
2	39.7	24.6	54.5	152	18	98	67	5,148	5,024
3	45.3	21.1	56.8	146	7	97.9	—	5,340	4,280
4	48.2	18.8	58.0	144	43	97.9	—	5,836	4,272
5	50.5	23.0	61.9	—	—	—	—	5,556	4,044
Average	44	26	59	—	—	—	—	—	—

* Percentage of own influent.

Activated Sludge Summary

Two important conclusions relative to the ability of activated sludge units to remove ABS seem warranted on the basis of experimental work conducted during a period of more than three years.

1. If the factors which govern ABS removal are any of those normally related to the sewage treatment efficiency of an activated sludge unit—aeration rate, solids concentration, BOD reduction, etc.—the degree of sensitivity is evidently so great that it is beyond the resolving power of laboratory and pilot activated sludge units. That is to say, it is not defined by the tests normally used to keep the fluctuations in an activated sludge system within limits acceptable to its sewage treatment purpose as measured by BOD and suspended solids reduction.

2. If the factors which govern the ABS removal can be isolated and controlled, a single-stage activated sludge unit should consistently remove 50 to 60 per cent of the influent ABS, while a removal of 70 or 75 per cent is feasi-

TABLE XV.—Reduction in ABS by Two-Stage Activated Sludge System with Added BOD from Raw Sewage Solids

Days	ABS Reduction (per cent)			Infl. BOD (mg/l)		BOD Reduction (per cent)		Solids Conc. (mg/l)	
	1st Stage	2nd Stage*	Over-all	1st Stage	2nd Stage	1st Stage	2nd Stage	1st Stage	2nd Stage
1	23.2	7.0	28.2	264	238	94.3	96.2	6,508	3,224
2	31.4	8.4	36.7	183	180	95.6	97.8	6,720	3,416
3	25.8	2.8	27.8	225	208	96.9	98.6	5,440	3,500
4	24.3	29.3	45.3	182	—	95.6	—	5,632	3,828
5	—	—	—	—	—	—	—	6,024	3,724
7	23.7	11.8	32.0	287	432	97.9	98.8	6,332	4,524
8	29.7	33.4	51.1	269	201	98.5	98.0	5,344	4,392
9	31.3	15.1	40.7	363	163	98.9	98.2	5,688	4,632
10	26.3	24.4	42.8	250	197	98.8	98.0	5,684	4,156
11	19.7	29.0	41.3	175	—	97.7	—	6,108	4,272
Average	26.2	18.2	38.5	244	231	97.1	97.9	5,948	3,967

* Percentage of own influent.

ble when a second-stage with added BOD is utilized.

High-Rate Trickling Filters

Two studies of the removal of ABS by trickling filters were run on the filtration unit shown in Figure 10. The equipment consisted of a 6-in. lucite column, 5 ft in height, and equipped with a suitable clarifier. Determinations of ABS removal were made by radioassay of filter influent and clarifier effluent. The results of studies at recirculation ratios of 3:1 and 9:1 are summarized in Table XVI, from which it is evident that although the filter efficiency was increased by added recirculation, no improvement in its efficiency in removing ABS resulted from the increases in the recirculation ratio. In both cases the ABS removal was approximately 25 per cent.

The data presented on trickling filters do not cover a sufficiently wide range of BOD loadings to establish conclusively the ability of the trickling filter to degrade ABS. Removals of 70 to 80 per cent have been reported in the literature (3). Further experimentation with the trickling filter is therefore desirable.

Surface Stripping

The most effective means of removing ABS studied in the investigation is the removal of ABS from the surface of sewage either as an intermediate or tertiary treatment process which is termed "surface stripping." Because frothing has been associated with sewage effluents and because it is a well established physical-chemical phenomenon that surfactants concentrate in the froth, investigations were made on ABS removal by frothing induced by aeration alone or in combination with a commercial foaming agent. A number of studies of the factors influencing ABS removal by surface stripping, methods of removing and destroying the stripped ABS, and the engineering and economic aspects of the process have been completed or are in progress. Results of these studies are

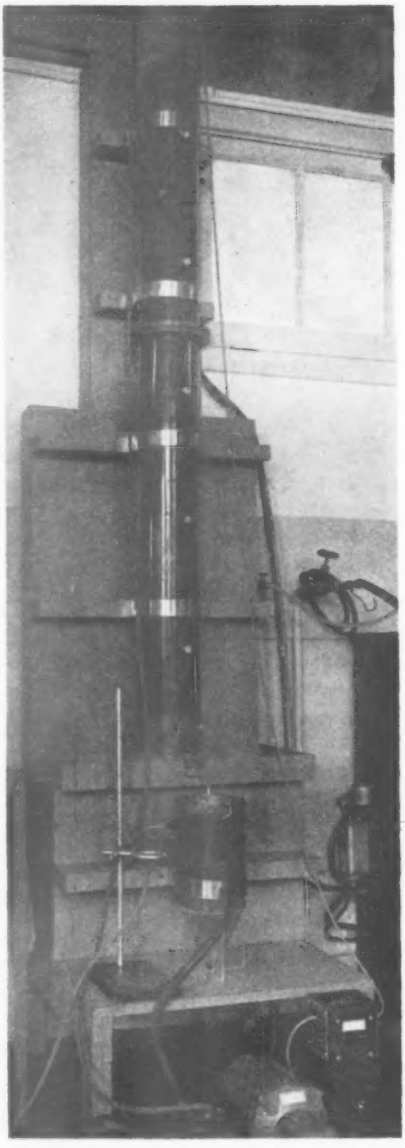

FIGURE 10.—High-rate trickling filter and clarifier unit.

TABLE XVI.—Removal of ABS[35] and BOD by Trickling Filter

Days	Recirculation Ratio = 3:1		Recirculation Ratio = 9:1	
	ABS Reduction (per cent)	BOD Reduction (per cent)	ABS Reduction (per cent)	BOD Reduction (per cent)
1	—	—	—	—
2	—	—	34.0	95.6
3	20.0	77.4	56.4	93.1
4	24.2	78.9	33.6	95.9
7	32.3	88.6	—	—
8	19.4	90.4	—	—
9	41.4	89.4	20.5	94.8
10	20.0	67.8	31.8	93.5
11	15.4	77.3	25.4	—
14	34.6	—	27.8	—
15	16.6	—	18.0	—
16	18.1	—	14.0	—
17	21.1	—	0.0	—
18	30.1	—	0.0	—
21	—	—	37.9	—
22	—	—	14.5	—
23	—	—	—	—
24	—	—	29.7	—
Average	24.7	88.9	24.5	94.6

not complete, hence only data indicative of the effectiveness of the method are presented herein.

Table XVII presents typical results of induced frothing experiments utilizing simple aeration and aeration in the presence of the commercial frothing agent, 2-octanol, for half-hour periods.

From Table XVII it is noteworthy that induced frothing of primary settling tank effluent by aeration alone effected an ABS removal of 83.2 per cent, and that about the same over-all removal was attained regardless of whether a portion of the ABS was previously degraded by activated sludge. With an added frothing agent this over-all reduction in ABS was increased to more than 90 per cent. However, the froth produced carried a large amount of entrained water and destruction of the ABS by flaming of the froth was not as readily accomplished as in the case of the drier froth resulting from simple aeration. In this latter case, continuous destruction of ABS by a waste gas flame has been accomplished with a loss of less than 5 per cent in over-all ABS removal.

It is concluded, therefore, from the foregoing results, together with subsequent and as yet unpublished data, that intermediate or tertiary treatment of sewage by methods which appear to be economically feasible can be utilized to remove from 80 to 90 per cent of the ABS in sewage should it become neces-

TABLE XVII.—Average Removal of ABS[35] by Induced Frothing

Material Tested	Treatment	ABS Reduction in Terms of		BOD Reduction (per cent)
		Own Influent (per cent)	Over-all (per cent)	
Settled sewage (Case 1)	Aeration only	83.2	83.2	—
Settled sewage (Case 1)	Aeration plus 2-octanol	91.9	91.9	—
Settled sewage (Case 2)	Aeration only	90.2	90.2	—
Effluent single-stage activated sludge	None	32.5	32.5	92.1
	Aeration only	73.4	82.1	—
	Aeration plus 2-octanol	92.1	94.6	—
Effluent two-stage activated sludge	None	44.0	44.0	97.5
	Aeration only	56.3	75.5	—
	Aeration plus 2-octanol	89.7	94.3	—

sary to remove more detergent than is normally degraded by activated sludge.

Summary and Conclusions

Investigations have been underway since 1955 of the effect of alkyl benzene sulfonate (ABS) on sewage treatment processes, of the ability of such processes to remove ABS from sewage, and of operational or process modifications which might be effectively used should ABS removal become one of the objectives of sewage treatment. This program, covering but one phase of the interrelationships between surfactants and water is still in progress. However, work on all three aspects of the objective has been completed, with results deemed worthy of presentation to those concerned with sewage treatment prior to completion of the entire study.

Experimental studies completed include those concerned with:

1. The ability of primary sedimentation to remove ABS from sewage.
2. The ability of activated sludge to degrade ABS, and the effect of operational variables on such ability.
3. The effectiveness of two-stage activated sludge units, both with and without BOD enrichment of the second-stage influent, in degrading ABS.
4. The feasibility of removing ABS by surface stripping, either as an intermediate or tertiary process.

Results of these and related experiments lead to a number of conclusions, some of which are probably subject to refinement as the investigation proceeds and as other researchers contribute the results of their investigations.

1. No evidence was found in the investigation to indicate that the concentrations of ABS found in domestic sewage threaten to render the sedimentation, activated sludge, or filtration units of a treatment plant incapable of performing the functions for which they are designed. No studies of sludge digestion were conducted.

2. Sedimentation is not an effective process for removing ABS from sewage, from 2 to 4 per cent being the normal reduction resulting from two hours of primary settling. If all suspended solids were filtered out, the maximum removal of ABS would be of the order of 10 or 12 per cent.

3. In prolonged experiments during which the BOD removal was constantly within a range of 88 to 97 per cent, ABS removals varied from 19 to 77 per cent. On separate occasions identical units operated on sterilized sewage of constant characteristics gave average ABS removals ranging from 40 to 55.5 per cent.

4. Greater average ABS reductions are generally achieved with high solids concentrations in the mixed liquor than with normal or low concentrations. Under optimum conditions solids concentrations in the 5,000 to 6,000 mg/l range may remove 60 to 70 per cent of the ABS present.

5. A single-stage activated sludge unit under 4- to 6-hr aeration should consistently remove 50 to 60 per cent of the influent ABS; while a removal of 70 to 75 per cent is feasible in a two-stage plant in which dispersed primary sludge is used to increase the BOD of the second-stage influent.

6. In the limited experimentation reported the trickling filter did not compare with activated sludge in efficiency of ABS removal.

7. Intermediate or tertiary treatment of sewage can be used to remove 80 to 90 per cent of the ABS in sewage should it become necessary to remove more than is normally degraded by activated sludge. In experiments with induced frothing by aeration alone and with aeration in the presence of 2-octanol, ABS removals of 83.2 and 91.9 per cent, respectively, were obtained from primary sedimentation tank effluent. Similar removals were obtained by surface stripping of activated sludge effluents in the same manner.

8. A continuous process of stripping ABS from sewage effluents by induced frothing and burning of froth with waste digester gas appears to be a feasible and highly efficient method of ABS removal.

References

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2. Weinberger, L., "Nitrogen Metabolism in the Activated Sludge Process." M. S. Thesis, Mass. Inst. of Tech. (1949).
3. Smith, W. S., "Removal of Anionic Synthetic Detergent by Percolating Filters." *Jour. and Proc., Inst. Sew. Purif.*, Part 2, p. 153 (1957).

MEETINGS OF INTEREST

1959

Aug. 27	**State Chamber of Commerce Water Supply Conference,** Abraham Lincoln Hotel and St. Nicholas Hotel, Springfield, Ill. J. G. Ronchetto, Illinois State Chamber of Commerce, 20 N. Wacker Drive, Chicago 6, Ill.
Sept. 8–10	**Annual Water and Sewage Plant Operators Short Course,** University of Maryland, College Park, Md. W. M. Bingley, 2411 N. Charles Street, Baltimore 18, Md.
Sept. 13–18	**American Chemical Society,** 136th National Meeting, Atlantic City, N. J. H. B. Gustafson, P. O. Box 5033, Tucson, Ariz.
Sept. 14–19	**Symposium on the Treatment of Waste Waters,** Kings College, Newcastle upon Tyne, University of Durham, England. Peter C. G. Isaac, Public Health Engineering Section, Dept. of Civil Engineering, Kings College, Newcastle upon Tyne, England.
Sept. 20–23	**American Public Works Association,** Olympic Hotel, Seattle, Wash. Robert D. Bugher, Executive Director, 1313 E. 60th Street, Chicago 37, Ill.
Sept. 21–25	**14th Annual Instrument-Automation Conference and Exhibit,** Instrument Society of America, International Amphitheater, Chicago, Ill. H. S. Kindler, Director of Tech. and Educational Services, 313 6th Avenue, Pittsburgh 22, Pa.
Oct. 19–23	**American Public Health Association,** Annual Meeting, Convention Hall, Atlantic City, N. J. Dr. Berwyn F. Mattison, Executive Secretary, APHA, 1790 Broadway, New York, N. Y.
Oct. 19–23	**American Society of Civil Engineers,** Annual Convention, Hotel Statler, Washington, D. C. W. H. Wisely, Executive Secretary, ASCE, 33 W. 39th Street, New York 18, N. Y.
Oct. 20–22	**National Conference on Standards,** American Standards Association, Sheraton-Cadillac Hotel, Detroit, Mich.

METROPOLITANISM AND SEWAGE HANDLING TECHNOLOGY *

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In the past ten years, several million homes have been constructed in areas inaccessible to community sewers. Under these circumstances, the Federal Housing Administration has been hard pressed by the problem of sewage disposal at individual residences. As tangible evidence of interest in the solution of these problems, FHA jointly with the Public Health Service financed a series of studies commencing in 1947 and extending through 1952. Many of the concepts contained in the "Manual of Septic Tank Practice" (1) are direct results of those early studies.

In an effort to improve the reliability of design procedures and evaluate new practices, FHA contracted with the Public Health Service's Robert A. Taft Sanitary Engineering Center to conduct another series of studies on a reimbursable basis beginning in the fall of 1956. This current series is directed toward a more efficient use of soil as a disposal medium for septic tank effluent. Thus far, major investigations have been made in 20 counties of 9 states. The following analysis of the problem of sewage disposal in metropolitan areas comes from direct observations and experience gained in the course of those investigations.

Problem

Prior to the 1940's there was good reason to believe that the major problems associated with the safe disposal of domestic sewage were solved. In general, the population to be served was either urban or rural, and the two techniques, the central sewerage system and the individual household system, were adequate for most situations. But since the mid 1940's, the United States has entered into an era of revolution in land development. Both the magnitude and the pattern of metropolitan growth are undergoing drastic changes. As a result, all phases of political and physical sciences dealing with metropolitanism are being adjusted to cope with the changing situation.

To deal effectively with sanitary engineering problems, it is necessary to comprehend the magnitude of the revolution and its influence on factors important to the solution of those problems. As with all revolutions, many individual trends can be identified, some minor, others major, but all lending momentum to the common cause. Actually, it probably started around the turn of the century when the rural population stopped growing. Since then the farm population has actually decreased while the non-farm population has increased by a factor of four.

Land Use

A later development in the urbanization trend is the changing pattern of land use. At first urban areas grew at a relatively slow rate, utilizing land adjacent to the established community. By 1950, however, the revolution was well under way, producing

* Presented at the Fifth Annual Wastes Engineering Conference, University of Minnesota, Minneapolis, Minn., Dec. 12, 1958.

drastic changes in the pattern of metropolitan growth. Speculative housebuilding with the subdivision type of land use is a product of the last decade. At first, subdivisions were usually located in the suburbs to escape high costs and high taxes but in recent years location in fringe areas has been by necessity. Currently, an inventory of vacant lots would show that building sites within corporate limits, especially those served by sewerage systems, are scarce and are already priced out of the speculative housebuilding market.

Another change involves the type of land use required to fulfill the desires of the modern family. One result of a rising standard of living is to make the nation one of home-owners. The percentage of owner-occupied dwellings rose from 44 per cent in 1940 to 55 per cent in 1950 and an increase to 60 per cent is expected by 1960 (2). In all probability, family income will continue to rise, and this factor coupled with installment financing will lower the age at which families can purchase their first home.

Access to Home Sites

To provide for home-ownership the vast majority of new houses will be built in the suburbs at an ever-increasing distance from the parent city. In this respect, the highway building program may have more impact on housing location than any other factor in history. Approximately $40 billion of the estimated $100 billion which will be spent on modern roads in the next decade will be spent in metropolitan areas. As a result, limited access expressways will lead from the countryside into the heart of all major cities. As time, not distance, is the major consideration of commuters, the expressways will make land available and attractive for housing at greater distances from the city. Clearing rights-of-way during the construction of the highways will generate more pressure for the suburban movement. It has been estimated that several hundred thousand houses per year will be demolished in the highway and urban renewal programs. It is paradoxical that improvement of the city destroys houses and becomes another factor in forcing people to the suburbs.

Population Growth

The impact of another major factor is yet to be felt. It is the unprecedented rise in the birth rate starting in the late 1940's. In 1940, the expert opinion was that the population of the United States had become relatively stationary and perhaps would even begin to decline. Even as late as 1946 a population of 153 million was forecast for 1960, and an ultimate peak of 164.5 million was predicted for 1990. The great increases in marriages and births following the war made these predictions appear ridiculous. The present population is in excess of 175 million and an estimate of 180 million now seems logical for 1960. In fact, during the past 10 years, population increase has consistently exceeded the estimates.

The increase in birth rate has had little effect on housing starts because the starts are more closely associated with family formation than with population increase. At present, people reaching the marriageable age are being drawn from the low birth-rate years of the 1930's, but the wave of children now in elementary and high schools will reach marriageable ages in the 1960's. As a result, it is believed that housing starts will continue at the present rate of about one million per year for the next few years. After that, there should be a steady increase with the possibility of two million or more starts per year in the 1970's.

Future Estimates

In summary, the concentration of the population in huge metropolitan

complexes, installment financing, the demand for home-ownership, expressways making land many miles from the parent city attractive for house building, and an unprecedented increase in the population of the country leads to this sobering conclusion. The explosive expansion of the standard metropolitan area is not a passing phase. Rather, it is the start of a major revolutionary trend that will continue at least into the 1980's.

To provide for adequate sanitary facilities of all types in a dispersed community of the proportions visualized is something for which present planners are entirely unprepared. The problem of sewage disposal is already acute (3). In fact, to provide for the proper disposal of sewage in an expanding suburban area from the time the first house is occupied until the area is fully developed is one of the most complex problems ever faced by the sanitary engineering profession.

Deficiencies of Present Technology

The present technology of sewage collection and disposal, limited as it is to either the central sewerage system or the individual system, is inadequate to meet the situation. This can be illustrated by examining the pattern and rate of metropolitan growth and attempting to apply currently acceptable solutions to typical situations. Communities no longer grow in neat concentric rings around the parent city, but leap-frog out along major highways in a patchwork pattern sometimes referred to as an "urban sprawl." This wheel-spoke pattern of growth creates four general situations:

1. Suburban zones and shopping centers that will in all probability become fully urbanized in a few years.
2. Isolated islands of high population density but limited in area, located so that many years will pass before the vacant land between islands is urbanized.
3. Areas of low population density caused by building homes on large lots where, because of zoning or location, full development is unlikely for many years.
4. Motels, camp and recreational facilities, consolidated schools, and other isolated installations.

Much frustration stems from the attempt to apply a science developed for two situations, urban or rural, to "growth" situations that are neither of the two. An appraisal of current practice leads to the conclusion that many costly restrictions on land development stem from lack of fundamental knowledge rather than from public health considerations. In the following discussion, deficiencies in knowledge are treated under five major topics. Information is not completely lacking. However, no comprehensive body of knowledge constituting generally acceptable technology exists for any of these fields. Although specific studies are not listed, research with the objective of developing an applied science for each of the following five topics should be pursued.

Interim Sewerage Schemes

Neither the large municipal system nor the individual household system are compatible with the first pattern of growth. When full urbanization within a matter of five or ten years is likely, acceptable schemes are needed to allow the permanent sewage handling system to grow step by step as the transition, from farm land to scattered subdivisions, and finally to complete urbanization, is accomplished. It is desirable to construct elements of the collection system as houses are built so that a final sewerage system can evolve in the same manner that roads and other utilities develop.

Within the framework of a general plan it should be possible to install tract sewers and laterals as each subdivision is constructed. Sewage from

a group of houses would then be concentrated at a strategic point. As the area developed these points could be joined by trunk sewers, and still later the trunk sewers could be connected by interceptors to carry the sewage to the permanent treatment plant. At each point of concentration a temporary facility would be provided to treat or handle the sewage in such a way that the public health hazard would be minimized.

Temporary Treatment

Such schemes as the use of temporary pump stations and force mains are being used to convey the sewage to an established system. Dry sewers and temporary individual systems are sometimes installed until the central system can be extended. In other schemes the sewage is treated and discharged near the central collection point. Stabilization ponds have recently come into use for this purpose and under proper circumstances hold much promise. There is immediate need for the development of other dependable, low cost, high performance sewage treatment plants which can be used to provide interim treatment.

The purpose of the interim plant and the conditions under which it is operated are sufficiently different from the conventional community plant to indicate a radically different concept of design and use. In that the plant will be replaced by a more permanent facility within the foreseeable future, first cost should be low and the possibility of salvage value should be considered. In spite of its temporary nature, careful construction is necessary because full growth of a suburban area takes time, and the plant may be required to serve five to ten years. In the general situation, dilution water at the plant outfall will be meager or non-existent. Therefore, the plant must perform at a very high level, and tertiary treatment or storage of the effluent may be required. The plant will be located in the vicinity of residences and it should either be attractive or inconspicuous. Odors or other nuisance must be held to a minimum. Satisfactory provisions must be made for the disposal of sludge. The cost of maintenance required by the plant and sewers must be modest. In the small plant, large volumes of clear storm water can cause serious difficulty. The collection system must be constructed with care to minimize infiltration. In this respect, too little attention is given to the construction of house sewers. As a general rule the total length of sewers connecting individual houses to the street sewers will be greater than that of all other sewers in the system. Therefore, the value of tight street sewers is diminished if ground water can infiltrate poorly laid house sewers. It follows that roof, foundation, and other storm drainage must be excluded.

Cost to Individual

Reflecting the inefficiency of interim systems, the charge per home for sewerage service will be high. However, the number of homes served will be small, and thus, the total operating budget will be small. The cost of interim sewage service should promote the establishment of a more efficient system. A great disservice can be done if home-owners are not required to bear the full expense of operating the interim system. It is presumed that such systems will be inefficient from an administrative standpoint, and therefore, the unit operating cost per house served will be high. It is evident that enthusiasm for plans to increase efficiency is in direct proportion to the anticipated reduction in cost. Even though they eventually pay for the service, in any event home-owners will support formation of districts or other schemes that will result in a re-

duced monthly charge. On the other hand, if a unified district will result in a higher monthly charge, it is difficult for the voter to appreciate the value of efficiency.

Small Permanent Treatment Plants

When it is probable that the area surrounding an island of high population density will not be urbanized for many years, the small sewage handling system may be justified as a permanent solution. In this instance appreciable capital investment can be made profitably in the treatment plant to minimize operating and maintenance costs. In that the system is intended to be permanent, a real problem exists in determining the type and number of small treatment plants that are economically justifiable and administratively acceptable. With proper information, this problem is amenable to economic analysis.

An increasing demand for small permanent plants is presented by schools, motels, trailer parks, recreational facilities, and other scattered installations. By their very nature, establishments of this type are located to serve a need, and that location is often many miles from a community sewage disposal facility. As evidenced by the concern of state and local sanitary engineers throughout the country, improper sewage disposal at such an establishment constitutes a serious public health hazard. As the nation grows, becomes more mobile, and has more leisure time to enjoy parks and other recreational facilities, the problem will become more acute.

A section of the "Manual of Septic Tank Practice" deals with schools, institutions, recreational areas, and other establishments. Likewise, a majority of the states have issued pamphlets with recommendations for schools and public buildings. In general, these publications are devoted to septic tanks, Imhoff tanks, and surface and subsurface filters. The origin of these recommendations, with modest refinement, dates back 25 to 30 years.

There is wide divergence in the requirements for plants for individual households, for the small community, and for other establishments. The volume, character, and pattern of discharge of the wastes are different. Conditions for maintenance and operation are different. The ease and extent of regulatory control varies greatly. For instance, a health officer could cause a restaurant to close for repairs to a malfunctioning plant, but an order to close residences for the same purpose would likely be ignored. Wastes characteristics, maintenance and operation, and ease and extent of regulatory control are all factors important to a rational technology to provide sewage disposal with reasonable economy. Investigation and research should be utilized to devise suitable schemes based on the nature of the general problems likely to be encountered and the application of modern science to the unit processes involved in treating and disposing of liquid wastes.

Individual Household Systems

A permanent demand for the individual household system is created by the construction of houses on large lots in the suburbs of metropolitan areas (4). The most common individual household system consists of a septic tank followed by soil absorption to dispose of the partially treated liquid. Largely as a result of the interest and support of the Federal Housing Administration a new technology is being developed to permit intelligent use of the septic tank soil absorption system. FHA has authorized an expenditure of more than $400,000 for reimbursable research contracts at the Robert A. Taft Sanitary Engineering Center in the past three years.

The present usefulness of the septic tank system is limited by the absorp-

tion characteristics of soil. Because at least half of the major soil groups in the country are relatively impervious, and because a demand for dispersed homes and large lots is increasing, there is need for workable schemes for individual houses built on impervious soil. It is possible that a different type of pretreatment would render sewage fit for disposal in soil now considered unsuitable for septic tank effluent. With dependable electric power readily available there is reason to believe that radically different sewage disposal appliances could be developed.

Several private concerns have attempted development of devices utilizing the aerobic principle. The interest of private capital in this endeavor should be stimulated, but its efforts are hindered by lack of definition of an acceptable effluent and the paucity of information pertaining to public health hazards associated with the disposal of effluent from these devices. In the development of these devices the emphasis has been on treatment rather than effluent disposal. With individual household units the basic problem is one of disposal of a large volume of liquid rather than sewage treatment in the conventional sense.

Alternate Media for Ultimate Disposal

The technology of treating and disposing of domestic sewage from American communities is based on the use of surface water for the final disposal of partially treated liquid. It has been convenient for inland communities to collect and dispose of their liquid wastes in rivers or lakes. The type and degree of sewage treatment, if any, is selected to prevent unsatisfactory conditions. In all cases, however, ultimate disposal is accomplished through the ability of the receiving body of water to purify itself.

In many suburbs a body of dilution water suitable for effluent disposal is not adjacent to new housing developments. The insistence on the use of surface water as the only acceptable waste disposal medium is placing a costly and perhaps unnecessary restriction on the orderly development of land. It is not only logical but imperative for sanitary engineering research efforts to be directed toward the development of other acceptable media for ultimate waste disposal.

It is evident that in the absence of an adequate body of receiving water, only three alternate disposal media exist: (a) the subsoil, (b) the ground surface, and (c) the atmosphere. All three alternatives are being used, sometimes intentionally and at other times by accident, but intentional or otherwise, fundamental knowledge required to use these media intelligently is lacking.

Surface Disposal

In many suburban areas dry ditches and storm water drainage courses are being used to dispose of partially treated sewage. Undoubtedly, in many cases, the fraction of waste that does not evaporate to the atmosphere or infiltrate into the soil receives a very high degree of treatment before it finally reaches a flowing stream. However, the degree of treatment required to eliminate the public health hazard is unknown. Surface discharge is relatively infrequent and for the most part is tolerated on a sub rosa basis. Should the practice become general, serious attention must be given to effluent standards and dependability of sewage treatment devices.

Evaporation

Evaporation and thus disposal in the atmosphere is an important factor in stabilization ponds under some climatic conditions. Even where evaporation is an insignificant factor, ponds can be adapted to the point where

effluent quality would place them in the category of disposal media. A stabilization pond can be considered as an artificial lake providing a body of dilution water consisting of treated sewage. The use of ponds represents the first important break with traditional methods of community waste disposal. In view of the urgency of the situation their development and exploitation should be pressed with vigor.

Soil Disposal

Soil is also being used extensively as a medium for disposal of waste. Although soil absorption systems are used almost exclusively at individual households, approximately four billion gallons of partially treated waste are disposed of in this manner each day. There is no real reason for limiting the use of soil to the individual system. However, little is known of the fundamentals of soil clogging and other factors governing efficient use of the soil. For instance, the septic tank is used almost universally to pretreat sewage in preparation for soil absorption, yet such anaerobic pretreatment has never been established as the most desirable.

Many experts agree that a major research effort should be devoted to facets such as the persistence of ground water contamination, the factors governing self-purification of ground water, the role of oxygen diffusion, evapo-transpiration, and other factors involved in the use of soil as a disposal medium as well as the mechanical aspects of transmitting liquid into the soil.

Small Installation Problems

With the exception of some of the primary steps such as screening and sedimentation, treatment of sewage depends on the biological processes of stabilization and purification. The economy of utilizing biological treatment for large volumes of sewage is probably beyond challenge. However, there is an ever-increasing demand for plants to serve individual households and small installations. The volume to be treated measures in hundreds rather than millions of gallons per day.

The problems associated with controlling biological processes are as complicated in small plants as they are in large plants. In most cases, however, the small installation cannot support the services of a full-time skilled operator.

A consequence of modern living is the appearance in sewage of synthetic organic compounds such as the active agents used in modern detergents. It has been common knowledge for some years that these compounds are highly resistant to biological degradation. The adverse effect on sewage treatment and the persistence of detergents in surface water have been noted and lamented, but little has been done to alter treatment processes or take other positive action to correct the situation. In spite of the problems created, it is likely that the use of detergents will continue, and furthermore, modern chemistry will produce further advances resulting in other biologically resistant chemicals in domestic sewage.

Sewage treatment is accomplished biologically by transferring dissolved and colloidal organic material to a solid phase, separating solids and liquid, converting separated solids to gas or reducing the volume of the solids to an insignificant bulk, and disinfecting or pasteurizing the effluent. Utilizing physical and chemical principles, it should be possible to incorporate these unit processes into an automatic, completely mechanized sewage treatment plant.

Economic Analysis

With new housing starts in excess of one million per year, the initial annual capital outlay for sewerage facilities to serve new houses is approximately one-half billion dollars. It is

likely that a modest effort in research leading to more efficient practice can result in savings many times the cost of the research. For instance, in a recent development of the FHA septic tank studies (5) it was conclusively demonstrated that the distribution box can be eliminated and the design of the soil absorption system can be greatly simplified. The application of this finding will result in better performance and an annual saving in first cost alone of more than six million dollars. Conversely, it is apparent that inefficient practices can cost the country a staggering sum of money, to say nothing of the danger and aggravation that is often generated.

With the development of a technology which provides solutions for the complete spectrum of situations which may occur in an expanding metropolitan area, the engineer will be confronted at times with a choice of several alternate acceptable solutions. A rational choice can be made through the use of economic analysis that integrates public health considerations and administrative costs with engineering design factors. An economic model has been proposed in a paper titled "The Status of the Technology of Individual Household Sewage Disposal Systems," now under consideration by the National Research Council, Committee on Sanitary Engineering and Environment, and to be published in a future issue of THIS JOURNAL. In order to apply the method to the solution of actual problems, the heretofore intangibles of public health administration and public health hazards must be evaluated.

Even with the paucity of information now available the economic analysis is proving its worth in determining the amount of money that can profitably be invested in tests to determine the size of soil absorption systems. Another interesting application is in determining the minimum lot size for use of individual systems when total cost including that of administration is the only factor involved in a choice with a community system.

Importance of Planning

A discussion of the problem would not be complete without considering the importance of planning. Metropolitan areas are faced with three demands: (a) a backlog demand created by failure to provide adequate facilities for new construction in the past 20 years, (b) a replacement demand for facilities wearing out or needing modernization, and (c) an expansion demand to accommodate the expected growth in population (6). The present nature of the first two demands has created sufficient pressure in many localities to get action started. However, with a few exceptions, plans to accommodate expansion are non-existent.

To be of maximum benefit, plans to accommodate expansion should be made for each drainage basin in the metropolitan area. In view of the many uncertainties a rigid master plan is probably impractical. A plan that defines the drainage basin, indicates the logical site for a treatment plant, the location and size of the main trunk sewers, and the probable type and density of development could become the basis for cooperative action between builders and health authorities. With a pattern to work from, house builders and authorities can determine the most desirable final solution for sewage disposal at a particular site. The initial sewers or other facilities can then be sized and located so that they become elements of the final system. Without a plan to work from, orderly growth of the sewerage scheme is impossible.

Summary

The dwindling farm population, demand for home-ownership, modern home financing, scarcity of land served by sewers, expressways, and a phenomenal increase in the birth rate are

all factors indicating that the problem of sewage disposal in suburban areas will become increasingly acute for many years to come. Application of acceptable sewage disposal schemes to the general situations developing in metropolitan areas leads to the conclusion that technology must be fortified to meet the changing situation.

Five applied sciences should be established to permit the common use of: (a) interim sewage handling schemes, (b) small permanent sewage treatment plants, (c) new or modified individual household systems, (d) alternate media for the ultimate disposal of partially treated waste, and (e) sewage treatment processes independent of biological activity.

Economic analysis and metropolitan planning must become a part of standard practice for sanitary engineers if costly and aggravating errors are to be avoided.

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QUARTER CENTURY OPERATORS' CLUB

The 1959 membership list of the Quarter Century Operators' Club has been mailed to all members. Fifty-seven members are listed on the current roster and it is believed that there are many others in the Federation who are eligible for membership.

The Club is an informal group comprising Active or Corporate Members of any Member Association who had been engaged in treatment works operation, on a full-time resident basis, 25 years prior to the date of their admission into the Club. A candidate need not now be engaged in treatment plant operation, but he should have a continuing interest.

Those interested in joining this unique Club can secure membership forms from the registrar: Henry Van Der Vliet, P. O. Box 281, Rutherford, N. J.

ACTIVATED SLUDGE TREATMENT AT EDMONTON, ALBERTA *

By Norman G. McDonald

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PRELIMINARY DATA

Local Statistics

Sewage treatment in Canada has not been given the same consideration as in many other parts of the world because of the low density of population and the presence of numerous rivers and lakes which have been used to advantage for dilution. At present, the largest complete treatment plant in Canada is the Edmonton plant, described herein.

Edmonton, Alberta, is the most northerly city of its size in Canada. It is about 675 miles farther north than Detroit, about the same latitude as Manchester, England, and Hamburg, Germany, but not as far north as Moscow, Russia, by 125 miles. Its altitude is approximately 2,200 ft above sea level. The city is situated in a protected position in the lee of the Rocky Mountains, giving an annual average precipitation of only 18.25 in. The climate is described as cold, temperate, but is not as severe as might be expected in a continental location at 53 degrees north. The average winter temperature is 13.7°F, and low temperatures of −30°F occur on the average three or four times each winter. Summers are usually pleasant, with an average July maximum of 74° and a minimum of 50°F.

The population of Edmonton has increased from 7,000 in 1904 to about 267,000 in 1958. The average rate of increase from 1930 has been 6 per cent annually. From 1948 the annual rate of increase has been 8 per cent, a rate considered faster than any other city of comparable size in North America and possibly in the world. This is to be compared with an average rate of growth of Canadian cities of 1.75 per cent per annum and 2 per cent per annum for the whole of Canada for the past 60 years.

Edmonton is located on the North Saskatchewan River, which flows from the Rocky Mountains through the provinces of Alberta, Saskatchewan, and Manitoba, into Lake Winnipeg, thence to Hudson Bay, through Nelson River. The records of flow for more than 30 years in the North Saskatchewan River at Edmonton indicate wide variations, as shown in Figure 1, the maximum being 204,500 cfs and the minimum 220 cfs. Minimum flows occur during the winter months when ice cover is present in thicknesses of 2 to 3 ft, and under these conditions the replen-

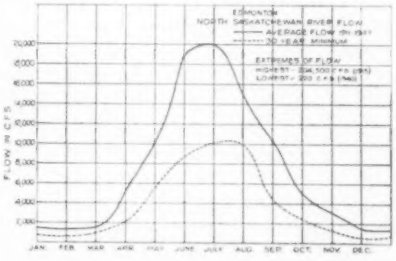
EDMONTON
NORTH SASKATCHEWAN RIVER FLOW
AVERAGE FLOW (30 YEARS)
20-YEAR MINIMUM
EXTREMES OF FLOW
HIGHEST - 204,500 CFS (1915)
LOWEST - 220 CFS (1940)
FLOW IN CFS.
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEP. OCT. NOV. DEC.

FIGURE 1.—Flow records for North Saskatchewan River at Edmonton.

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

ishment of oxygen from the atmosphere is negligible. During the summer months the river is capable of absorbing a great deal of pollution due to the high flows and dissolved oxygen content, consequently, the requirements for a high degree of treatment during the winter months only are contrary to conditions encountered in warmer climates.

Waste Sources and Criteria

The problem of sewage treatment for Edmonton is aggravated (a) because of the condition of the receiving stream with its very low winter flow and ice cover, and (b) because the heaviest industrial loads occur during the winter months. The industrial wastes come primarily from several meat packing plants. Most of the animals, particularly cattle, are brought in for slaughter directly from pasture at the beginning of winter to avoid the cost of housing and feeding. This means that during the latter part of November and December the slaughterhouse kills are normally at their maximum. As a result, the industrial load is approximately equal to that from the rest of the city and the raw waste BOD concentration is about double that which would be expected from average domestic sewage.

Based on surveys of the North Saskatchewan River by the Alberta Provincial Department of Health DO and coliform limits were established. These were based on a minimum dissolved oxygen content in the river of 4 mg/l and a maximum coliform concentration which would be acceptable for a municipal water supply with treatment. The standards and limits arrived at were: (a) the coliform concentration at Fort Saskatchewan, 20 miles downstream, to be less than 20,000/100 ml, (b) the BOD loading by sanitary sewage to be less than 12,000 lb/day during the period of November 1st to April 15th and 60,000 lb/day for the remainder of the year, and (c) the concentration of oils and greases (ether extractable materials) in the effluents to be less than 25 mg/l.

From these data the allowable winter BOD loading was established assuming a winter flow of 600 cfs with an initial DO of 8.9 mg/l.

Sewage Handling System

Edmonton is divided by the North Saskatchewan River into two parts, nearly equal in size. The remote southwesterly area is served by a small primary treatment plant which will serve a population of 50,000 and will be provided with secondary treatment when necessary. For the main part of the city consideration was given as to whether one or two treatment plants should be constructed and it was decided to establish one main sewage treatment plant at the easterly limit of the city, on the south bank of the river, to which the sewage will flow by gravity. Actually, at the time of making the report in April 1953, the site selected for the sewage treatment plant was outside the city limits, but extensive development and annexations since that time have placed the site within the city.

Two main interceptors to carry 2½ times the dry weather flow were designed for alternate sides of the river, the north interceptor to cross the river and join the south interceptor near the treatment plant site. The north interceptor consists, for the greater part, of a 78-in. diameter concrete-lined tunnel, 100 to 120 ft deep. The river crossing consists of an overflow and valve chamber and two coal tar enamel-lined steel pipes running as siphons under the river bed. The siphons can be operated alternately and individually so that inspection and repairs can be made readily. The provision of two pipes with steep hydraulic gradients assures that the ve-

locity during a part of any day will be high enough to prevent the accumulation of grit.

The sewage collection system throughout the city is of the combined type except for some of the westerly areas, above the intake for the city water supply.

TREATMENT DESIGN

Sewage Design Data

During the fall and winter of 1955 sampling and flow estimates were made on the main sewer outlets of the city. The flows were computed by measuring the depth of sewage in the sewer, the measuring points taken at a constant slope section of the sewer. The depth of flow on the main north side trunk sewer, which is 10 ft-6 in. in diameter, had to be measured through a manhole approximately 120 ft deep. This was achieved by the use of an electrical contact device attached to a plumb bob at the end of a measuring tape. At the moment the contacts touched the liquid surface a reading was obtained on a galvanometer. The samples were collected at the sewer outlets. During the sampling and flow measurement program on the north side the temperatures ranged from about + 10° to − 20°F, thus ensuring at all times that dry weather flow existed.

The final treatment plant loading was arrived at from the accumulated data shown in Table I.

In order to determine the design degree of removal for primary treatment, an existing primary treatment plant with a grit channel, mechanically-cleaned fine screen, and settling tank with sludge collector was deliberately loaded to give an average detention period of 1½ hr. These tests, along with the sampling of the main trunk sewers, indicated an average suspended solids removal of 54 per cent and a BOD removal of 33 per cent.

As a result of water supply intake and cooling water adjustments in connection with the power generating plant, the sewage temperature at the treatment plant ranges from 55 to 60°F throughout the year.

General Plant Design

The sewage treatment plant was designed with special consideration for economy, consistent with the provision of permanent structures and efficient operation. As a result of these requirements the design loadings may, in some cases, be considered unusually

TABLE I.—Sewage Data from Sampling Program

Source of Contribution	Flow (mgd)	Avg Suspended Solids*		BOD*	
		mg/l	lb	mg/l	lb
North side trunk	8.94	498	37,200	548	40,900
South side trunk	3.10	576	14,860	566	14,600
Balance of flow	6.80†	376†	21,300	325†	18,410
Total	18.84	—	73,360	—	73,910
Weighted average‡	—	467	—	470	—

* From 7-day period.

† Flow estimated from water consumption; SS and BOD values estimated from type of areas served.

‡ Weighted averages for 5-day work week are 550 mg/l SS and 540 mg/l BOD.

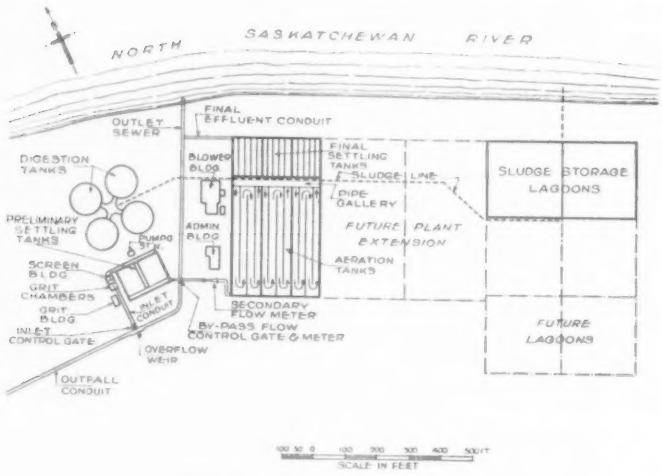

FIGURE 2.—Plan of treatment plant.

heavy and the estimated removals optimistic.

The plant, as shown by plan in Figure 2 and by aerial views in Figures 3 and 4, has been designed to give complete treatment by activated sludge to an average dry weather sewage flow of 24 mgd, containing an average of 470 mg/l each of suspended solids and 5-day BOD, serving a population of 250,000 persons. The estimated removals were 95 per cent both for suspended solids and BOD. Assuming a contribution of 0.17 lb BOD per person the equivalent population, including industrial wastes, would be 560,000. During the five-day work week the pollution load would be increased by about 25 per cent as shown in Figure 5 and the equivalent population would be about 700,000 persons.

The plant has been designed in such a way that it can conveniently be operated as step aeration, conventional activated sludge, and other modifications. The primary treatment section was designed to carry a maximum flow of 60 mgd, or 2½ times the average dry

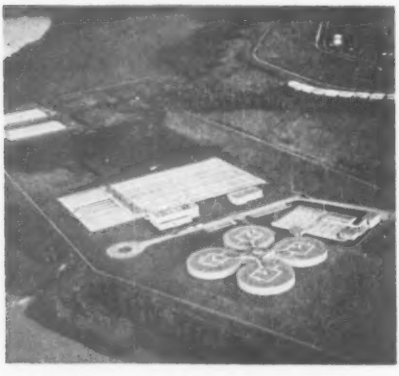

FIGURE 3.—Air view of treatment plant.

FIGURE 4.—Treatment plant in middle background showing proximity of residential areas.

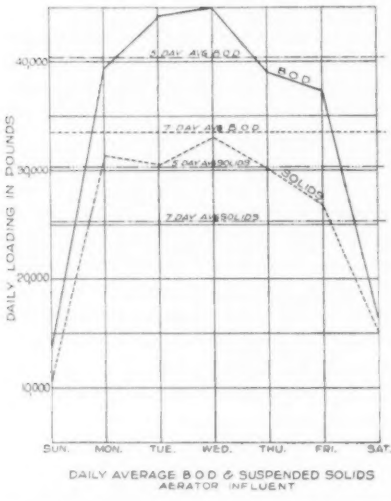

FIGURE 5.—BOD and suspended solids loadings expected in the treatment plant.

weather flow. The secondary treatment section was designed to handle a maximum flow of 36 mgd, or 1½ times the average dry weather flow. In addition to the suspended solids and BOD it was anticipated that the grease content of the sewage might be as much as 150 mg/l as contributed by meat packing wastes.

The plant consists of aerated grit tanks, comminutors, rectangular primary settling tanks, digestion tanks for either single or two-stage operation, aeration tanks using diffuser nozzles, and rectangular final settling tanks. Sludge collectors in both the preliminary and final tanks are arranged for grease removal. Lagoons are provided for the storage and disposal of digested sludge.

Each section of the primary treatment stage has two units. There are four digestion tanks, and the secondary treatment stage has three separate units which can be operated independently to permit the carrying out of three variations of treatment at the same time.

Primary Treatment

The flow to the plant is controlled by an electric motor-operated sluice gate and all storm flows in excess of the plant capacity are bypassed over the main weir to the river.

The two aerated grit tanks have a detention period of five minutes at average flow. The grit is removed from the tanks by an electric hoist-operated grab bucket (Figures 6 and 7) and trucked from the site. Grit storage and housing for the bucket unit are provided in the grit building, which is heated. The truck is loaded inside the grit building to facilitate cold weather handling. Large amounts of sand from streets are included in the grit received at the plant. Cinders, because of their relative light weight, are troublesome to remove in the grit chambers. As a result some are carried over into the primary settling tank.

The screen building houses two comminutors. At the time of design there were limited restrictions only on the type and quantity of industrial wastes acceptable at the treatment plant. Strengthening of these limitations was anticipated, but in the meantime the variety of waste constituents included complete animal stomachs, in-

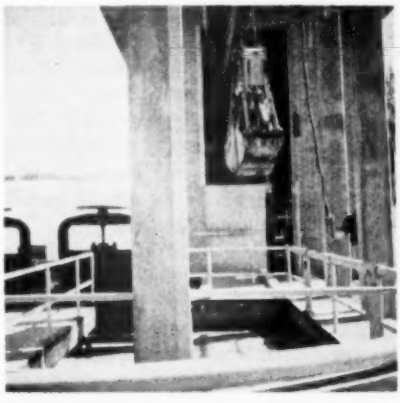

FIGURE 6.—Grit chamber showing grit removal bucket in operation.

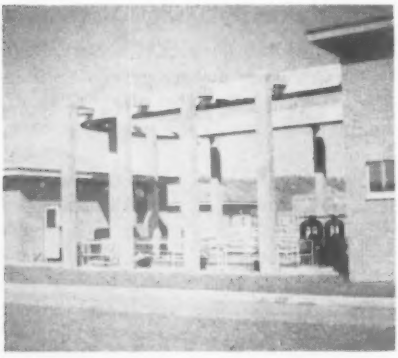

FIGURE 7.—Grit chamber showing monorail system for grit removal hoist.

testines, horses' hoofs and legs, pigs' toenails, paunch manure, feed bags, chickens, feathers, and large amounts of grease. As a result these materials imposed severe loads on the primary units.

Channel aeration is provided upstream and downstream of the screens, as well as in the influent conduit to the preliminary settling tanks.

The two preliminary settling tanks have a detention time of 1½ hr at average flow. The drive units are inside the building and transfer the driving power through the walls. The plant is designed for the synchronized collecting, pumping, and transferring of sludge.

The grease is skimmed by means of the return collector flights and rotary type troughs and it is pumped to the digestion tanks during the sludge pumping cycle. The grease is delivered to the digestion tanks along with the raw sludge by means of a scum pump, started automatically by a level switch located in the scum hoppers.

The sludge and scum lines, which are 6-in. in diameter, have been in continuous operation for two years without clogging. The raw sludge meters, which are protected by heating coils, were removed after two years for inspection and were found to be almost entirely clean. The plant was laid out so that the sludge lines would be short. Hot water circulation was also provided because of the difficulty which has been experienced in other plants. The use of this has not yet been required.

The sludge pumping is arranged for the simultaneous removal of raw sludge from the settling tanks and transfer from the primary to secondary stage digesters, so that overflow liquor is only passed back to the settling tanks from the second stage digesters. Overflow liquor from the primary digesters is pumped into the secondary digesters. The liquor pump is actuated by a level switch. At the digesters, the raw sludge is mixed with the heated recirculated sludge and discharges on the top of the scum blanket.

The sludge piping system is arranged so that any one of the four digestion tanks may be used for primary digestion. Gas recirculation is provided for all four tanks, although it is used only in the primary tanks.

The four digestion tanks are each 100 ft in diameter and have a volume of 250,000 cu ft each and are designed with a minimum amount of interior piping. The only pipes which appear inside each tank are the raw and circulated sludge line, which is attached to the roof of the tank, and the digested sludge withdrawal line, which is supported on the floor of the digester. The tanks are heated by means of individual hot water heat exchangers with circulating pumps for continuous flow, such pumps and exchangers being housed in the digestion tank control building. The tanks are supported on cast-in-place concrete piles and are designed to withstand an uplift on the cone of up to 12½ ft of water, resulting from high river levels.

The plant is heated by hot water boilers normally burning sludge gas, with a natural gas standby supply. The gas production has reached 600,000

cfd during the winter season and, on account of the high load of grease, may be 1,000,000 cfd when the plant is operating at full capacity.

Secondary Treatment

Blower Plant and Air System

The secondary treatment is basically a diffused air activated sludge process, the air being provided by means of four rotary positive displacement type blowers having an installed capacity of 53,000 cfm (Figure 8). The blowers are driven by synchronous electric motors with horsepower ranges from 400 to 600.

In view of the extremely cold weather conditions it was considered necessary to provide an air preheater for the main air supply to the blowers. This heater is designed to heat the incoming air to $-20°F$ or higher, so that the air leaving the blowers will have a minimum temperature of 60 to 70°F.

As previously stated, the design assumed that the secondary treatment section will not be required to operate in the summer period when dilution by the river flow is considered to be adequate to accommodate the primary treatment effluent. In view of the realization that algae would be a maintenance problem in porous diffusers, sparger-type air diffusers were selected. Since only coarse air filtration is necessary glass fiber units were found to be sufficient but necessary due to the type of material carried in suspension in the air, particularly during the spring and summer months. This was confirmed by operating tests during the summer wherein there was experienced a substantial buildup on the filters, mostly fluff from poplar trees.

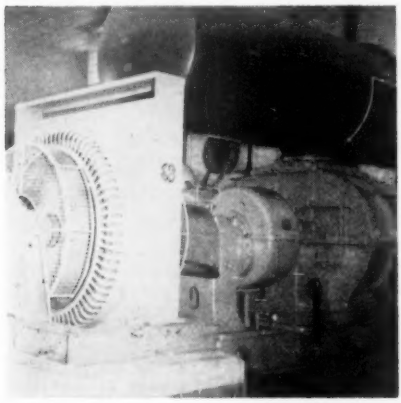

FIGURE 8.—One of the blower units.

Air enters the blowers through umbrella-shaped intake hoods situated on the top of the blower building. The intake was located high to avoid drawing in the mist or fog which rises from the warm sewage during cold weather. It was found that tempered glass was necessary in floodlights located 35 ft above the aeration tanks because of moisture collection in cold weather.

The blowers are of the rotary displacement type and are provided with inlet and outlet snubbers. The total pressure drop as measured on the two snubbers, ranged from 30 in. of water on the 400-hp unit to about 23 in. on the 600-hp units. The total pressure loss in terms of power for inlet and outlet snubbers averaged 12.5 per cent.

Aeration

The aeration tanks, which are 20 ft wide and 15 ft deep, were designed with numerous inlets to allow for step aeration, conventional activated sludge, or as either of two modified processes. The BOD design loading was 60 lb/day/1,000 cu ft, for total time and was 75 lb/day/1,000 cu ft for the 5-day work week when the sewage was stronger. The air supply was based on an average of 800 cu ft per pound of BOD removed. Each of the three aeration tanks contains four passes with round-the-end flow, the fourth pass discharging into the mixed liquor conduit to the final settling tank. The air

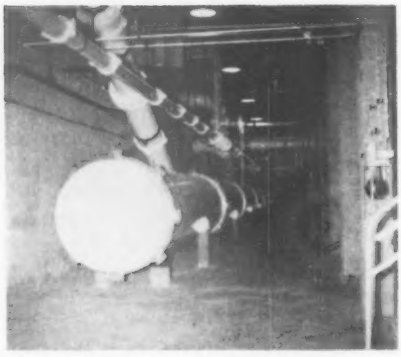

FIGURE 9.—Main air header.

supply is provided by means of two main air headers (Figure 9) on the division walls between the first and second, and the third and fourth passes. The sewage is normally fed in steps to the tanks through a conduit constructed on the center partition wall between the second and third passes, with seven step gates located on each side of this conduit. The settled sewage can also be delivered to the inlet end of the first, second, and fourth passes, or any combinations desired.

With three independent units, which may be operated individually, three variations of a process or three different processes may be carried on at the same time and their efficiencies and economics evaluated. The only common connection to the secondary section is the settled sewage and final effluent conduits. The air headers located on the partition walls of the tanks are galvanized steel pipe and the downpipes from the shut-off valve are galvanized cast iron pipes.

Provision was made for sprays using plant effluent for the reduction of froth on the third and fourth passes (Figure 10). Storage tanks and feed pumps were also installed for the application of defrothing agents. Early operating experience indicated that the sprays alone have satisfactorily kept down the froth, except on some weekends when the solids became very low and more air than necessary was used.

Final Settling

The final settling tanks are rectangular, 110 ft long, designed with an average overflow rate of 910 gpd/sq ft and a detention period of 2.4 hr based on average sewage flow. Sludge is collected at the outlet end and grease is skimmed and removed from the inlet end and pumped to the preliminary tanks with the waste sludge.

The final tank effluent passes over V-notch weirs into three sets of cross troughs which split the discharge to gullets at both sides of the tank.

Sludge Disposal

There is little demand for fertilizer in this area as the soil contains a lasting supply of nitrogen and is not in need of humus.

There are no suitable local land disposal areas available and in view of the cost of burning or drying, the Provincial Department of Health gave the City permission, for a period of two years, to dump the digested sludge into the river during the higher flow periods. The tentative minimum flow

FIGURE 10.—Fourth pass of aeration tank showing defrothing sprays and mixed liquor outlet.

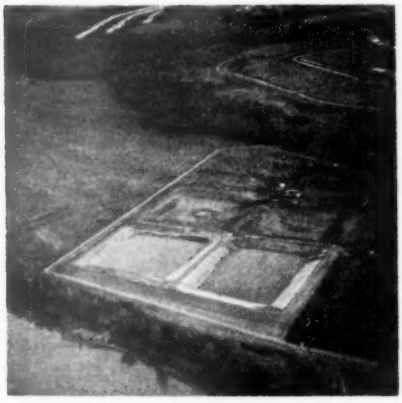

FIGURE 11.—Sludge storage lagoons.

is established at 5,000 cfs. This means that the average dumping period may extend for about six months and that storage is necessary for the balance of the year.

Two earth lagoons were constructed in 1957 at the easterly limit of the plant site, a distance of 1,200 ft from the digestion tanks (Figure 11).

One requirement was that all sludge from the digesters had to pass through the lagoons before disposal in the river. This arrangement would permit visual inspection of the sludge before it was discharged to the river.

Important problems here were to maintain the moisture content during the storage period to assure liquid conditions for ready discharge and to prevent the formation or buildup of great thicknesses of ice. In this connection, the prevention of subsoil infiltration is a problem and investigation is underway to provide economical surface soil coating.

The defrothing spray water pump is interconnected into the sludge line for flushing when required and for providing water for the hoses for emptying the lagoons.

Construction Costs

The treatment plant was constructed in the years 1955 to 1957 during a time of maximum cost. To demonstrate these costs, for the aeration and final tanks the average concrete price, including cement and reinforcing steel, was $42.00 per cubic yard.

The cost of the complete plants, including landscaping, roads, engineering, inspection, etc., was approximately $41/2 million. Of this the primary treatment section, including the digestion tanks for the whole plant, cost about $1½ million, and the secondary section, including the blower and heating plant, administration and laboratory building, and sludge lagoons cost about $3 million.

Actual per capita construction costs do not lend themselves to valid comparison because of the high proportion of industrial waste load. However, based on the design equivalent population the cost is about $8 per capita load.

OPERATION

Primary Treatment

During the early operating period a few difficulties were experienced in the primary treatment section, the chief one of which was in the screening building, where the comminutors were overloaded by the excessive amount and character of solids. The greatest difficulty was caused by the pigs' toenails, which are about the same size as the clear spacing between the bars and when they became wedged between the bars were difficult to remove. The lowering of the velocity in the grit chamber and modifications on the outlet weirs have permitted a more efficient removal and greatly reduced the problem. When one of the two comminutors is down for repair, the re-

maining unit is inadequate. Provision for emergency overflow was made and this feature has been found to be necessary, although sludge pumping problems are intensified.

During the startup of the primary part of the plant it was found that, with the baffled inlets to the primary settling tanks, large amounts of solids were being deposited directly downward into the cross collector channel and very little sludge was actually being carried down the tank. This condition quickly overloaded the cross collectors. The baffles were temporarily removed to allow distribution of the heavy solids. These solids consisted primarily of paunch manure, a very fibrous material. During these early days of operation an examination of the sludge in the cross collector channel indicated it to be extremely gelatinous in nature to the extent that frequently it would not flow to the pump suction.

The plant operators were instructed to gage their raw sludge pumping by observations in the sampling sinks. The sampling pipes are located, one level with the main tank floor and the other level with the bottom of the cross collector channel. During the sampling sink observations, due to this gelatinous type of sludge, the sludge formed an arch. During this period the lower pipe at the bottom of the cross collector channel would sometimes indicate clear liquid, whereas the upper pipe would indicate a heavy sludge.

Preliminary tests to determine the amount of grease indicate that it exceeds 150 mg/l during the fall and early winter months. Since there is intermittent operation of the sludge and grease collectors, grease freezes on the surface of the tanks in the winter, even though the temperature of the sewage is 60°F. Under such conditions the grease layer has to be broken up before being collected.

Sludge pumping is carried out by means of centrifugal pumps of the bladeless impeller type. When the comminutors are overloaded the screenings, including sticks and other debris, flow over the top of the screens and into the settling tanks, and thence to the sludge pumps. This has made it necessary to clean out the sludge pumps following such periods.

During two years of operating the digesters, no serious difficulties have been experienced. The tanks are heated to a temperature of 95°F and there has been no buildup of scum. Gas recirculation has been maintained in the first stage of digestion, the second stage being left quiescent in order to have an overflow liquor with a minimum of solids. As the result of the high solids and grease content of the sewage the gas production is unusually high, having reached a maximum rate of 600,000 cfd during the second year. When the south interceptor is placed in service a 30-per cent increase in organic matter, and gas production, is expected.

Secondary Treatment

Breakin Period

The completion of the laboratory was six months behind schedule and consequently for this period the plant had to be operated by visual inspection, assisted by the infrequent analyses of sewage and sludge samples made by a commercial laboratory. During the early weeks of operation variations in the voltage caused many shutdowns in the blowers and equipment. The snubbers on the discharge side of the blowers also required some repair. During the many interruptions in the air supply the activated sludge deteriorated and on several occasions became septic. However, when the air supply was restored the sludge recuperated quickly.

Another difficulty which has taken place in a number of complete treat-

ment plants, particularly when they have been operated for some time as primary treatment, was the complete filling of the primary settling tanks with sludge. This condition resulted from attempts to concentrate the sludge beyond reasonable limits in both the settling tanks and in the digesters. Such tests as could be made at that time indicated that the settled sewage going to the aeration tanks contained two to three times as much solids and BOD as was in the raw sewage. This condition was corrected in about three days by continuous pumping of the sludge.

On inspection of one of the aeration tanks it was found that approximately 25 per cent of the air diffusers were clogged. This was attributed to the frequent shutdowns of the blowers due to power failures and the heavy solids concentrations being carried in the tanks. On one occasion the suspended solids reached about 10,000 mg/l in the first pass.

Test Run

When the laboratory was ready for service a 5-wk test run was conducted using laboratory control procedures. Sampling of the raw sewage was neglected and the operating results indicated herein refer to secondary treatment only. It was assumed that the primary treatment removes approximately 50 per cent of the suspended solids and 33 per cent of the BOD. It was therefore estimated that the suspended solids in the raw sewage were double those indicated herein as settled sewage or aeration tank influent and the BOD in the raw sewage, roughly 50 per cent greater.

As the average flow of sewage to the plant was two-thirds of the designed capacity at the time of the test period, or 16 mgd, one of the three secondary units was taken out of service and drained in order that the two remaining tanks might be operated at their design capacity. During the experimental period one of the primary settling tanks was also taken out of service in order to increase the loading on the secondary section in an effort to establish maximum loading limits. For the 5-day work week the average flow was approximately 17.5 mgd.

There is a wide variation in loading during any 24-hr weekday period, as shown in Figure 12. From these curves it can be seen that the BOD concentration varies over a range of about 9 to 1. The comparison of BOD concentrations and flow pattern is also shown. Nearly all the industries operate on a single shift basis and this is shown in the curves.

Figure 13 indicates the return sludge rate variations compared with the curve formed by the product of sewage flow and settled volume percentage. This figure also indicates the variation in mixed liquor concentrations and sludge volume index throughout a typi-

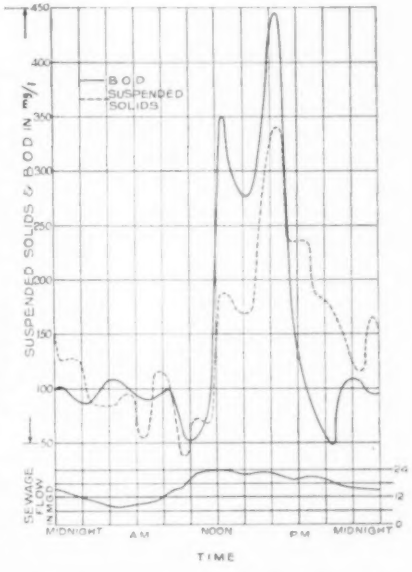

FIGURE 12.—Twenty-four hour variation in suspended solids, BOD, and flow—as influent to the aeration section.

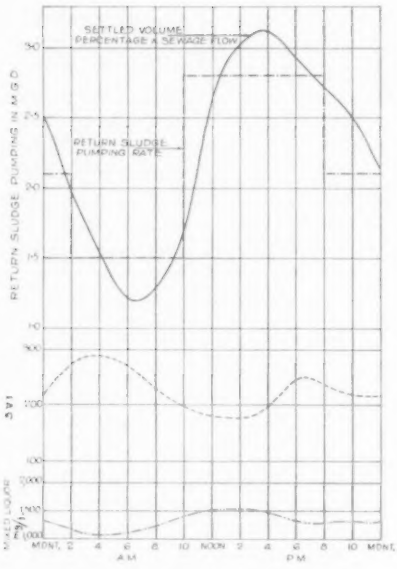
SETTLED VOLUME PERCENTAGE A SEWAGE FLOW
RETURN SLUDGE PUMPING RATE
RETURN SLUDGE PUMPING IN M G D
SVI
MIXED LIQUOR
MDNT. 2 4 6 8 10 NOON 2 4 6 8 10 MDNT.
A.M.
P.M.

FIGURE 13.—Effect of variable return sludge rate on mixed liquor concentration and sludge volume index.

cal 24-hr period. It was found that after the return sludge rates were adjusted the mixed liquor concentrations remained reasonably constant.

Waste sludge pumping is not continuous but has been arranged for the period when the maximum load enters the final settling tanks, about 9 hr after the settled sewage enters the aeration tanks. At this time the load on the primary settling tanks is relatively light; therefore, a more even loading is obtained over the 24-hr period.

Since the 7-day weighted average is about 83 per cent of the weighted average for the 5-day work week (Figure 5), it was necessary to shut down one of the primary tanks to obtain design loadings for test. In this way the load on the two secondary units was increased to a maximum of 150 per cent of the design BOD load.

The average BOD removal as indicated in Figure 14 is approximately 83 per cent up to a loading of about 17 lb BOD applied per 100 lb solids and about 96 per cent from 17 to 44 lb per 100 lb of sludge solids, corresponding to a variation in sludge age from about 6 to 2.3 days.

Figure 15 indicates power consumption in kilowatthours per pound BOD removed based on BOD applied daily per 100 lb of sludge solids after deducting the power loss through the snubbers, which amounts to 12½ per cent of the power supply to the blowers. The rising curve to the left of the diagram was obtained during weekends when the loading on the plant was very low but the supply of air was maintained at the average rate. This curve indicates that the average kilowatthour consumption per pound of BOD removed for loads varying from 30 to 50 lb BOD per pound of

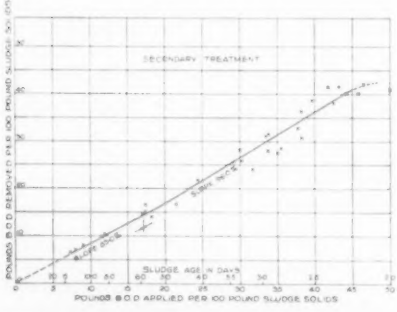

FIGURE 14.—BOD removal for various levels of sludge solids loadings.

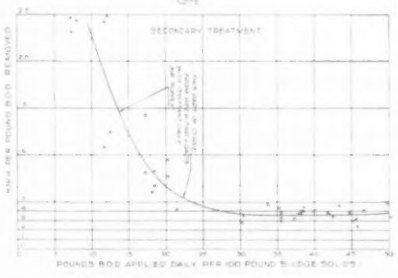

FIGURE 15.—Power consumption for various BOD loadings.

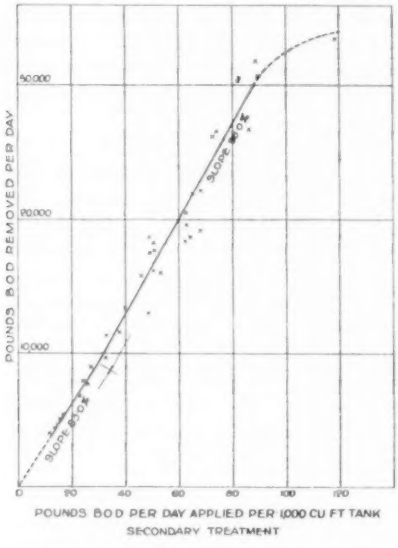

FIGURE 16.—BOD removal for various loadings in terms of aeration volume.

sludge solids was 0.36 kwh, which at 0.6¢/kwh costs 0.216¢/lb of BOD removed. It is apparent that there would be some saving in the cost of power by the reduction of air during the weekend periods.

Figure 16 indicates the range of BOD loading per 1,000 cu ft of aeration tank volume. The removal efficiency averages about 83 per cent up to 30 lb BOD and 96 per cent from 30 to 90 lb BOD per 1,000 cu ft.

Figure 17 indicates the number of cubic feet of air at normal temperature and pressure required per pound of BOD removed based on pounds of BOD applied per 100 lb of sludge solids. This curve indicates the best operation to be around 33 to 40 pounds BOD applied per 100 lb of sludge solids, representing a sludge age of 3 to 2½ days. For these conditions the air required is about 720 cu ft/lb of BOD removed.

Figure 18 indicates the variation in dissolved oxygen content of the mixed liquor on the basis of BOD loading. The dissolved oxygen was measured in the aerator effluent for a 24-hr period, whereas the BOD curve is typical of the loading entering the aeration tanks, which is responsible for the time lag. These curves are merely to show a trend since they do not represent data from the same day.

Experimental operation was discontinued after five weeks because at that time (July) the flow in the river was high and the operation of the second-

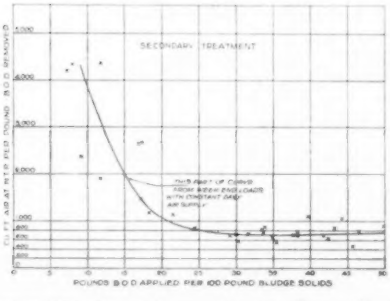

FIGURE 17.—Air requirements for various BOD loadings.

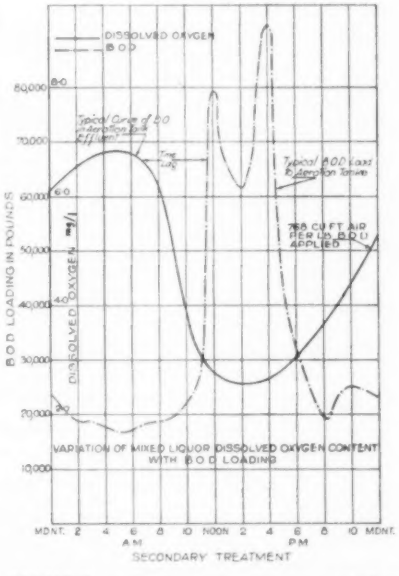
DISSOLVED OXYGEN
B O D
Typical Curve of B O D Aeration Tank Effluent
Time Lag
Typical B O D Loss in Aeration Tanks
738 CU FT AIR PER LB B O D APPLIED
DISSOLVED OXYGEN mg/l
B O D LOADING IN POUNDS
VARIATION OF MIXED LIQUOR DISSOLVED OXYGEN CONTENT WITH B O D LOADING
MDNT. 2 4 6 8 10 NOON 2 4 6 8 10 MDNT.
A M
P M
SECONDARY TREATMENT

FIGURE 18.—Dissolved oxygen variation with BOD loadings.

ary treatment was not required. However, it was thought necessary to train the operating staff and to establish sufficient data to permit the plant to be put into service the next week on a sound and economical operating basis. The experimental work established the fact that the plant will carry loads higher than those for which it was designed, with over-all efficiencies of above 95 per cent for both solids and BOD. During the experimental operation period it was also possible to train the permanent operating personnel.

The first operation used the step aeration method. It is planned for investigative studies in the future to utilize the three separate units in such a way that test runs of the three variations of the process may be carried out simultaneously and independently with no mixing of the return sludge.

Acknowledgments

R. A. G. Simmons, Director of Gore & Storrie Limited, was project engineer. The work was carried out in conjunction with the City of Edmonton engineers consisting of D. B. Menzies, City Commissioner in Charge of Works, J. D. A. Macdonald, City Engineer, and R. H. Nicolson and G. Duncan, Assistant City Engineers. Carl Taylor was Resident Engineer of Construction and is now Director of Sewage Plant Operation.

GRADUATE FELLOWSHIPS

The National Science Foundation has announced plans to award approximately 1,000 Cooperative Graduate Fellowships in Science during the 1960–61 academic year. This program is in addition to the regular Graduate fellowship program.

Awards will be announced to the approximately 150 cooperating educational institutions by the NSF on March 15, 1960. A wide range of sciences is included in the program.

Applicants will apply through the participating institution which they expect to attend as Fellows. The annual stipend is $2,200. Fellows electing a tenure of an academic year will receive 9/12 of the annual stipend. The stipend may be supplemented by the institution up to $800 annually or $600 for an academic year. In addition to these stipends, tuition and fees will be paid.

Applications for Cooperative Graduate Fellowships must be received by the Dean of the Graduate School of the participating institution by Nov. 6, 1959.

For further details write to the Graduate School of a participating institution or to the Fellowships Section, National Science Foundation, Washington 25, D. C.

Industrial Wastes

SPRAY IRRIGATION OF DAIRY WASTES *

By Gerald W. Lawton, George Breska, L. E. Engelbert, G. A. Rohlich, and Nandor Porges †

Associate Professor of Sanitary Engineering, Research Assistant, Department of Soils, Professor of Soils, and Professor and Director of Hydraulic and Sanitary Laboratory; all of the University of Wisconsin, Madison, Wis.; and Head, Whey Utilization Investigation, Eastern Utilization Research and Development Division, U. S. Department of Agriculture, Philadelphia, Pa.

This is a report of work done under contract with the U. S. Department of Agriculture and authorized by the Research and Marketing Act of 1946. The contract is being supervised by the Eastern Utilization Research and Development Division of the Agricultural Research Service.

The rural or semi-rural location of many small dairy plants, together with the high strength of their liquid waste, usually present a special problem in the disposal of such waste. Frequently the only drainage is a roadside ditch or a small stream, neither of which may be satisfactory for the removal of untreated or partially treated waste.

The cost of conventional aeration or trickling filter type treatment plants usually makes them impractical for the small dairy plant. Most investigators are of the opinion that irrigation provides a simple and economical method for disposal of these wastes wherever sufficient land with suitable topography and soil is available (1).

Dennis (2) noted that the first spray irrigation installation started operation in 1947 in Pennsylvania for disposal of cannery wastes, and that spray irrigation of dairy wastes was initiated two years later in Tennessee. Schraufnagel (3) stated that there are now about 30 milk plants in Wisconsin using spray irrigation as a means of waste disposal. McKee (4) summarized the results obtained from the spray irrigation of dairy wastes at eight typical installations and concluded that the method has proven to be satisfactory. Kuhlman (5) favored the use of small holding tanks in order to maintain the wastes as fresh as possible. Breska *et al.* (6) reported on earlier phases of the studies reported herein. Other articles on spray irrigation of dairy wastes have appeared during the past few years (7) (8) (9) (10).

Procedure

The purpose of the study was to determine the effectiveness of spray irrigation as a method for the disposal of dairy plant wastes. The project included both the soils and the engineering aspects of the problem. The

* Presented at the Pennsylvania Sewage and Industrial Wastes Assn., Annual Meeting, University Park, Pa., Aug. 13–15, 1958.

† Deceased April 1959.

selections of the sites for the study were made with the cooperation of the Wisconsin Committee on Water Pollution. The soil and the availability of the sites were prime considerations in the selection, but for more details reference is made to Breska *et al.* (6). Six sites were selected, one of which was found later to be impractical, and the data obtained at another were extremely limited because of indefinite suspension of irrigation.

Early in the study routine information covering the milk intake, cheese production, depth of well, size and type of pump used, size of sump, type and quantity of irrigation equipment, and size of area being irrigated was obtained at each plant.

The daily volume of waste at each plant was determined by average drawdown rates in the sumps, coupled with duration of pumping. The duration of pumping was determined from clocks wired in parallel with the pump motor. At four of the plants water meters were installed at the well to check water usage.

Samples were obtained by the use of samplers developed during the project. Basically, these consisted of a splash plate offset over a funnel leading to a refrigerated sample bottle. A one-half inch line from the discharge side of the pump allowed a small stream of waste to fall on the splash plate, which was so adjusted that during a 24-hr period an appropriate quantity of waste was diverted to the sample bottle.

The sanitary quality and chemical composition of the wastes were determined. Soil samples from irrigated and unirrigated areas at each site were taken with an auger to determine particle size distribution and chemical analysis, and with a core-type sampler for physical measurements.

General data relative to the milk plants and their waste systems are given in Table I. The milk intake at all plants is moderately low as is the volume of waste. At Plant D the waste volume is extremely low, apparently because of careful use of water, good housekeeping, and complete separation of whey from other wastes. The waste volumes are based on drawdown pumping data with the exception of Plant C where the record keeping by the operator was very erratic. At that plant it was necessary to assume that the water meter readings represented a close approximation of the waste volume.

The cost of the irrigation equipment varied widely, since existing equipment was used for parts of the systems and construction labor was supplied by the owner in some installations. In general, however, the costs were moderate as compared to conventional types of treatment plants. The cost of four

TABLE I.—General Data for Five Milk Processing Plants and Their Wastewater Handling Systems

Item	Plant Designation				
	A	B	C	D	E
Milk intake (avg lb/day)	20,500	10,600	20,000	13,500	33,500
Waste volume (avg gpd)	4,300	1,135	1,770	380	5,900
Cost of irrigation system ($)*	837	800	1,550	400	2,300
Acres irrigated:					
Total	0.97	0.213	0.65	0.018	1.15
Each setting	0.194	0.213	0.216	0.006	0.33
Pumping rate (avg gpm)	11	15.2	19.7	6	34
Pumping duration (avg min/day)	391	75	90	63	174
Application rate (avg in./hr)	0.13	0.16	0.20	2.3	0.23

* Excluding land cost.

TABLE II.—Average and Range in Cation and Anion Content of Certain Milk Processing Plant Wastes in mg/l

Plant Designation	Nitrogen		Phosphorus		Potash		Sodium		Calcium		Magnesium		Chlorides	
	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
A	—	—	17.1	6.5–27	57.8	26–118	166	103–216	76	46–92	49.6	32–60	180	128–278
B	170	93–319	132	33–194	138	31–452	374	282–642	76	43–101	40.6	20–140	264	104–710
C	180	108–298	59.7	24–105	160	54–388	433	98–675	78.6	47–105	34.9	13–60	494	160–943
D	58	19–110	35.2	16–62	46.6	16–147	255	168–329	57.9	32–107	35.7	19–49	162	57–354
E	43	10–111	31	12–77	37	4–62	470	183–796	66	44–94	37	24–60	559	186–1,000

other systems (excluding land) in Northern Wisconsin varied from $1,200 to $2,400.

The extent of the irrigated areas showed wide variation from plant to plant. At Plant D there was appreciable runoff to a cover area, hence the 0.018 acre is not truly representative. The application rate at this plant was roughly ten times that at the other plants; therefore, the runoff was not entirely unexpected.

Elemental Composition of the Wastewater

The chemical composition of milk plant wastes is extremely variable (Table II) and was found to vary not only with the time of sampling during a given day but also from day to day. These data emphasize the fact that grab samples have relatively little value for waste composition determinations. The nitrogen, phosphorus, and potassium content of the wastewaters is much higher than those usually found in municipal sewage. It is believed that the major source of the nitrogen is from the milk spilled or lost during processing, since no other source of nitrogen was observed. If this is true, then the differences in the average nitrogen content of the waste from a given plant is a fairly reliable check on the amount of milk lost during processing. From the nitrogen analyses it is evident that there is wide variation between plants in this respect.

The high phosphorus and potassium content probably comes from the cleaning compounds used in the plants. Many of these compounds are high in phosphorus or potassium or both. Here, again, the variability in the average phosphorus and potassium content of the wastes from the different plants is striking. This may be a reflection of the differences in kind and quantity of the cleaning compounds used. Because the water probably would be the major source of the calcium and magnesium, much less variability was found in the average values of these cations in the wastes from the different plants.

With the exception of sodium, the concentrations of the nitrogen, phosphorus, and other elements found in the wastes present no problem from the standpoint of spray irrigation. In fact, they can contribute markedly to the nutritional requirements of the crop being irrigated, as was evident at two sites (B and D).

The potential dangers of excessive amounts of sodium in an irrigation medium, particularly where fine textured soils are concerned, are well known. Although this problem was recognized, the high sodium content found in the wastes from the plants studied was not expected. The major source of sodium in the wastes is from the salt (NaCl) used in the plant. The wide variation in the sodium content of the wastes between plants would tend to indicate that with reasonable care the sodium content of the wastes could be greatly reduced. It is worthy of note that at one plant when the owner was absent for a few days the sodium content of the waste more than doubled.

The deleterious effects of sodium in the wastewater on soil aggregation or structure are not only dependent on the amount of sodium applied but also on the amount of other cations present. From the many studies carried out on the quality of irrigation water in relation to its use on western soils, the following formula (11) has been used for determining the suitability of the water:

$$\text{Percentage Na} = \frac{\text{Na} \times 100}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}}$$

where cations are in gram equivalents per million. To be suitable for irrigation of western soils, the equivalent percentage of sodium should not exceed 80, nor should the total concentration of cations, in equivalents per million, exceed 25. The percentage of sodium in the wastes included in this study ranged from 63 for Plant B to 44 for Plant E, thus indicating that they would be safe from this standpoint. Wastes from three of the plants, however, had total concentrations of cations which exceed the recommended permissible limit. The average total cation equivalents per million in the waste from Plants B, D, and E were 29.8, 27.0, and 28.3, respectively. Wastes from the other two plants averaged well below the recommended permissible limit with respect to the total cations. It is believed that in the more humid regions a fairly high salt concentration in itself does not constitute a serious problem because of the greater amount of leaching in the soils of these regions.

Soil Analyses

The analyses of soil samples taken the second year of irrigation are presented in Table III. These tests indicate that a substantial increase in all ions has occurred in the soil, particularly in the 0-to-6-in. layer. On the soils that were low in available phosphorus and exchangeable potassium, the grass crop exhibited a marked improvement resulting from these nutrients in the wastewater.

Exchangeable calcium and magnesium contents are not presented because even though large additions were being made via the waste, the changes in the soil calcium and magnesium contents were relatively minor. Large amounts of these ions are normally present (on the order of several thousand pounds of calcium and 500 lb of magnesium per acre-half foot). However, the importance of the calcium and magnesium in the waste in counteracting the deleterious effect of sodium on the soil should not be minimized, as explained later. As expected, sodium and chlorides exhibit the greatest increase in the soil. Chlorides and sodium are normally low in soils of the humid region unless recently fertilized or heavily pastured. In the latter case large amounts of NaCl are added to the soil via the animal droppings when they are receiving liberal amounts of salt. This probably accounts for the relatively high sodium content of the unirrigated soil at site B. The relatively high chloride content of the unirrigated soil at site D is believed to be the result of lateral movement, since the chloride ion is one of the few ions that readily moves with the soil water. Several more years of irrigation will be needed to determine whether soil sodium content will reach harmful levels or whether equilibrium will occur before this happens. From the studies on quality of irrigation water in western states it appears that the sodium is not present in the wastes in harmful amounts.

Soil Tests with Sodium

The harmful effects of sodium on the physical condition of the soil are shown in Figure 1. The differential treatments were as follows:

1. Sample at left was leached with 500 ml of distilled water.
2. Middle sample was leached with 500 ml of city water, containing 70

TABLE III.—Influence of Milk Plant Wastes on Acid Soluble Phosphorus, Water Soluble Chlorides, and Exchangeable Bases in the Soil

Soil Depth (in.)	Acid Soluble P (mg/l)		Water Soluble Cl (mg/l)		K (mg/l)		Na (mg/l)	
	Irrig.	Unirrig.	Irrig.	Unirrig.	Irrig.	Unirrig.	Irrig.	Unirrig.
				(*a*) PLANT A				
0–6	42.0	23.3	52.0	8.0	186	164	127	20
6–12	28.1	7.0	25.0	8.0	157	160	67	25
12–18	28.8	10.4	24.0	10.0	165	119	46	24
18*–24	36.6	7.6	28.0	8.0	310*	180	44	34
24*–30	62.0	27.4	20.0	6.0	290*	205	41	33
30*–36	75.0	55.8	16.0	8.0	300*	193	41	36
36*–42	103.0	69.4	16.0	8.0	233*	175	39	33
42*–48	124.0	72.0	8.0	8.0	200*	183	38	37
				(*b*) PLANT B				
0–6	96.7	62.3	83.0	48.0	250	90	213	128
6–12	51.7	51.3	59.0	27.0	134	70	52	93
12–18	57.3	51.0	48.0	20.0	174	95	56	55
18–24	58.8	51.0	44.0	22.0	182	106	53	40
				(*c*) PLANT C				
0–6	72.9	37.4	390	12.0	168	72	447	26
6–12	56.7	37.2	280	11.0	72	51	268	23
12–18	54.1	35.8	295	22.0	53	48	185	23
18–24	39.8	33.9	231	16.0	50	62	104	27
24–30	39.8	44.0	214	17.0	62	62	108	22
30–36	37.9	45.0	181	19.0	54	85	92	27
36–42	64.3	44.3	230	20.0	62	97	118	29
42–48	47.7	44.8	215	21.0	63	92	110	27
				(*d*) PLANT D				
0–6	68.8	46.7	28.0	6.0	347	265	152	22
6–12	61.1	28.4	30.0	24.0	222	118	109	29
12–18	28.9	15.6	42.0	33.0	179	156	118	27
18–24	22.7	13.8	36.0	36.0	178	165	106	58
24–30	19.0	30.7	28.0	40.0	180	192	110	74
				(*e*) PLANT E				
0–6	43.0	15.3	52.0	12.0	111	94	143	30
6–12	10.8	21.2	32.0	8.0	72	58	217	13
12–18	13.0	22.4	72.0	19.0	53	60	178	12
18–24	17.0	23.2	80.0	22.0	64	127	106	19
24–30	20.2	22.0	55.0	28.0	53	95	109	16

* Till or rock encountered in one of the excavations, therefore these values represent only one profile.

mg/l Ca and 53 mg/l Mg, to which 1,000 mg/l Na as NaCl had been added.

3. Sample on right was leached with 500 mg/l distilled water containing 1,000 mg/l Na as NaCl. After the differential treatments had been made, the soil in each funnel was leached with 500 ml of distilled water except for the

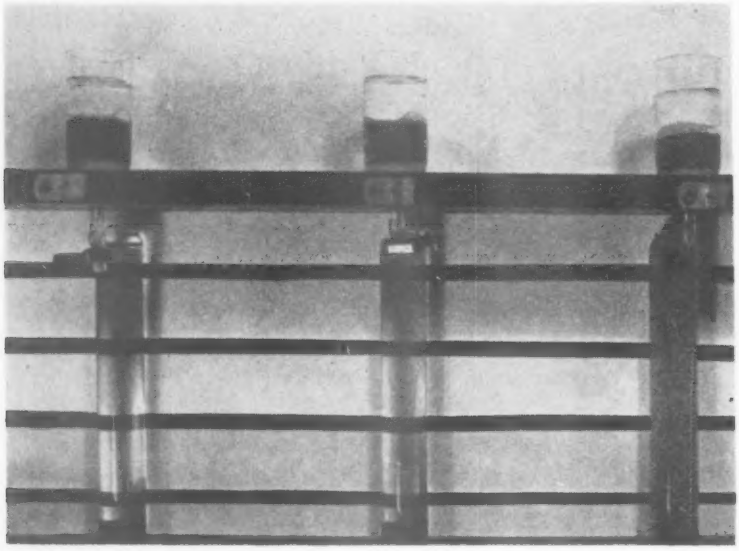

FIGURE 1.—Test apparatus showing soil structure as affected by sodium in the irrigation water when in the presence of calcium and magnesium.

third sample. In this case the soil became virtually impervious after about 250 ml of water had passed through. The soil structural breakdown in this test is evident not only in the appearance of the soil but also in the turbidity of the leachate. The turbidity is the result of dispersed soil particles passing through the cotton filter. The soil in the middle funnel exhibits only slight dispersion, as evidenced by the slight turbidity of the leachate. The beneficial effect of calcium and magnesium in irrigation water containing sodium can be explained as follows.

Soil clays, because of their negative charge, hold a large amount of cations in exchangeable form. When sodium constitutes about 15 per cent of the total exchangeable cations, the soil clays begin to disperse and dispersion increases with an increase in sodium content. When the soil is irrigated with water containing only the sodium cation, replacement of the other cations occurs until a high percentage of the exchangeable cations is sodium. Depending on the sodium content of the irrigation water, it may be many years before any noticeable deterioration of soil structure occurs. Also if sodium chloride or sulfate is present in the soil solution, it serves as a strong electrolyte and no dispersion occurs until it has been leached out by rains. Once the sulfates or chlorides have been leached, dispersion is very rapid if the soil clays contain a high percentage of sodium. Calcium and/or magnesium are more tightly bonded to clay than is sodium. Hence the presence of relatively small amounts of these cations in the irrigation water will have a marked depressing effect on the adsorption of sodium by the clay. Also, if the calcium and magnesium are present as the chlorides or sulfates, any sodium in the soil water remains in the chloride or sulfate form until leached from the soil. For example, in the laboratory test shown in Figure 1 the soil leached with city water containing 1,000 mg/l

sodium contained less than a third as much exchangeable sodium as the soil irrigated with water containing the same amount of sodium but no other cations (NaCl in distilled water). Soils that receive large additions of sodium, but only small amounts of calcium and magnesium, via the irrigation route, are benefited by applications of calcium sulfate at a rate of two or more tons per acre every few years.

Analytical Control Characteristics

Analytical characteristics of the wastes usually associated with wastewater treatment control, Table IV, also show extreme variations between plants and within each plant depending on the time of sampling. High concentrations of organic matter were indicated by the values found for BOD, COD, and volatile residue. Undoubtedly the main source of this organic material was milk spillage and the dumping of whey into the wastewater. Good housekeeping and efficient operation of a milk plant can markedly reduce the strength of the wastes, as shown by the relatively low BOD and low volume of waste at Plant D. In contrast, the waste from Plant B has 3 times the volume and approximately 4 times the concentration of that from Plant D, or about 12 times as much oxidizable matter from approximately the same milk intake.

The pH and alkalinity values similarly showed wide variations, indicating differences in the freshness of the wastes as they are applied to the soil. The average pH values were rather low for all wastes, but at Plant B the values were consistently low, undoubtedly due to the presence of appreciable lactic acid, indicating that active bacterial decomposition was regularly taking place in the holding tank before the wastes were applied to the soil. Such a condition is conducive to the development of odors at the irrigation site. Odors at Plant B were more common than at the other plants. In general, the low pH values were encountered during the summer when biological activity was more rapid.

For summer operation the use of a smaller holding tank, more complete pumpage from the tank, and more frequent cleaning should reduce the extent of biological decomposition of the waste before being sprayed, thus lessening the possibility of odors. For winter operation, however, a tank large enough to hold a full day's flow of the waste is frequently more desirable in order that manual operation of the irrigation system does not become burdensome.

The suspended solids content of the wastes was relatively high and rather variable. All plants were equipped with screening devices for removing large particles from the waste, but the

TABLE IV.—Analytical Characteristics of Milk Processing Wastes Usually Associated with Wastewater Treatment Control

Item	Plant A		Plant B		Plant C		Plant D		Plant E	
	Avg	Range	Avg	Range	Avg	Range	Avg	Range	Avg	Range
BOD (mg/l)	1,752	860–4,740	4,790	1,849–9,440	4,310	1,980–9,100	1,280	435–2,220	936	400–1,620
COD (mg/l)	—	—	4,520	1,467–11,500	7,800	3,740–15,320	1,703	552–2,830	1,241	366–1,880
Ammonia (mg/l)	—	—	19	1–68	36	20–76	15	2–40	7	1–31
Organic N (mg/l)	40	31–55	151	92–251	144	88–222	43	17–70	36	9–80
Alkalinity (mg/l)	—	—	359	0–582	81	0–272	505	0–1,088	249	0–389
pH	—	—	5.6	4.0–7.2	4.8	4.2–5.7	6.8	4.6–9.5	6.4	4.1–8.7
Total solids (mg/l)	—	—	5,450	3,296–11,434	6,490	3,540–11,990	2,280	1,208–3,326	2,653	1,000–8,610
Total volatile solids (mg/l)	—	—	3,800	749–9,404	4,740	2,444–9,988	1,350	554–2,346	1,240	365–3,720
Total suspended solids (mg/l)	—	—	1,025	510–1,800	1,040	600–1,940	361	273–502	619	220–1,980
Volatile suspended solids (mg/l)	—	—	998	488–1,540	910	500–1,840	303	200–390	561	220–1,720

FIGURE 2.—Dairy waste spray irrigation site showing ponding on newly seeded, poorly drained soil.

fines remained in the liquid which was sprayed. This leads to the proposed possibility that excessive amounts of these solids would tend to decrease the permeability of the soil and might lead to the development of odors. Good screening operations are essential to prevent clogging of the spray nozzles, especially during cold weather when a clogged nozzle quickly becomes a frozen nozzle. The wastes having high BOD values also showed high suspended solids content, indicating general inefficiency in the operation of the dairy plant itself. The suspended solids were almost completely volatile, indicating the loss of milk products in the form of cheese curd and various solids formed during decomposition in the waste holding tank.

Irrigation Rates

When estimating land needs for the disposal of wastes by crop irrigation, the dairy plant operator is interested in the average daily amount of waste that can be applied to a given area. Obviously, there are no hard and fast rules that can be applied by all dairy plants for predicting loading rates, because these rates will vary from site to site with variations of kind of soil and underlying strata, nearness to the water table, and climatic conditions. With the plants under study, variations between fields in safe loading rates were quite striking. At Plant C the soil was sandy in texture and the water table was at a depth of about five feet. There were no dense clay layers in the profile. Consequently, when the irrigation line was left in the same position for over a two-month period during the summer of 1956, no ponding or damage to the crop resulted. In contrast, at Plant B where the field being irrigated was silt loam overlying a fairly tight clay, runoff occurred almost every day shortly after irrigation was begun. However, because the irrigated portion of the field was at the head of a long draw, no ponding, and consequently no damage to the vegetation, resulted. It should be pointed out that because of this situation the area actually used for disposal at site D was much

larger than the specific area covered by the sprinklers (.006 acre).

The objectionable results of over-irrigation are evident in Figure 2. This site is not one that was under measurement, but is one of the sites included in a survey of a larger number of existing irrigation disposal systems. The soil is a silt loam overlying a very slowly permeable clay at a depth of two feet below the surface. Since the topography is level, objectionable ponding resulted. This field had been seeded a short time before the date of this photograph and outside of the irrigated area the vegetation was beginning to cover the soil. However, in the irrigated and ponded areas, the vegetation was completely killed. It is evident that, when soils and topographical conditions such as shown in Figure 2 exist, irrigation or loading rates will be largely governed by transpiration and evaporation (about 0.2 in./day during the growing season in the Wisconsin area).

Although some plants are better adapted than others to a restricted soil-oxygen supply, no plant will live long when the soil is water-logged with media containing as much organic material as those encountered in this study. On the other hand, the large amounts of easily oxidizable materials which occurred in the wastes constitute no serious problem when the irrigation system is well managed. Thus, it appears desirable to observe the crop under irrigation to make a final evaluation of design application rates. The health of the crop is one good criterion to use in judging whether excessive application rates have been used.

Winter Irrigation

Year-round irrigation was carried on at three of the plants under study. During the winter months this resulted in an ice sheet of about 18 in. around the sprinklers. In all cases the irrigation pipe had been raised off the ground two feet or more. Special precautions for pipe drainage were necessary to avoid damage to the irrigation system. Also, the plant operators

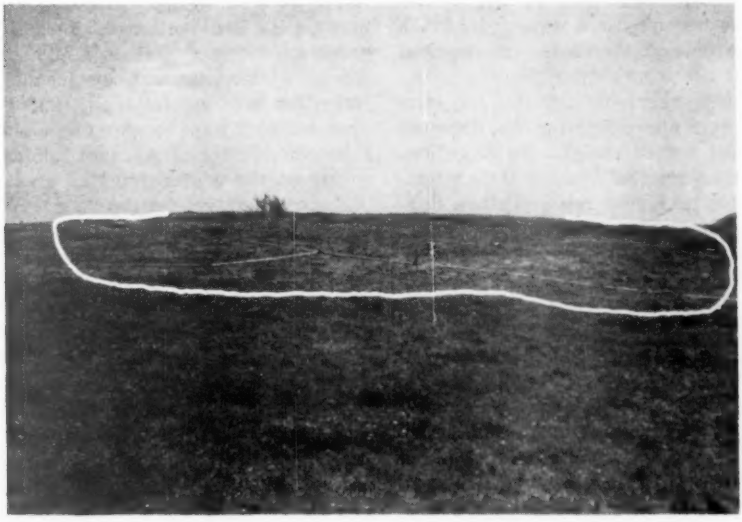

FIGURE 3.—Irrigation field showing crop injury (within the imposed line) as the result of a winter ice sheet.

FIGURE 4.—Same field as in Figure 3, showing recovery of grass crop by July following winter irrigation.

found that, because of the inherent dangers to the irrigation system, manual operation during the winter months was almost a necessity. Much more attention, therefore, was required during the winter operation.

In the spring before ground temperatures were above freezing, the thawing ice sheet caused runoff. No objectionable odors resulted because the air temperature remained relatively low during the period of thawing. By the time air temperatures were high the ice sheet had disappeared.

In all cases the original vegetation (mostly quack and blue grass) was very slow in recovering or was killed out completely in the area covered by ice. At site C, a level field, the grasses never did return and it was necessary to reseed the area killed. At site E the crop was very slow to recover (note enclosed area, Figure 3), but by July there was no difference between the area covered by ice and the uncovered areas (Figure 4). The latter site differed from site C in that it was on a fairly steep slope, and this may be the explanation for the differences encountered. It is likely that, where winter disposal by means of irrigation is being followed, the plant operator may have to plan on re-establishment of the crop the following spring on the winter-irrigated area.

Some operators in northern Wisconsin are using spray irrigation for spring, summer, and fall disposal, and are switching to other methods for winter disposal. At one of these plants the cooling waters are discharged to a roadside ditch and the strong wastes to septic tanks during the winter. At another plant winter disposal is accomplished by ridge and furrow irrigation with good success.

Conclusions

1. Spray irrigation appears to be a practical, economical, and satisfactory

method of disposal of dairy wastes where the irrigated area is properly selected and reasonable care is exercised in the operation of the system.

2. The volumetric loading and the cation loading appear to be the principal design factors when considering spray irrigation. The BOD loading is much less significant than it is in the design of biological treatment systems.

3. Reasonable predictions of loading or irrigation rates of a given site may be made when soil conditions, type of cover crop, depth of water table, etc., are known. However, final design application rates can best be determined by observance of the crop under irrigation.

4. The waste-holding tank, during summer operation, should be small (perhaps 2 to 3 hr maximum detention time), should be emptied completely during each pumping period, and should be flushed frequently to remove accumulations of solids which will otherwise cause objectionable odors.

5. From a mechanical standpoint, winter operation of spray irrigation systems is possible in areas comparable to the latitude of central Wisconsin, but it must be assumed that a complete kill of the cover crop will occur. However, the irrigation operation may be reasonably carried out by having alternate plots available in order that reseeding may be accomplished readily.

6. An evaluation of the effect of runoff from the ice cover during winter and from the spring thawing of the ice cover itself should be made at each site, based on the dilution available by the stream and on other factors peculiar to the site.

7. Hot wastes that are damaging to the cover crop may be successfully irrigated by elevating the spray nozzles, thus allowing the waste to cool as it falls.

8. In some irrigated areas having poor absorption characteristics, the use of tile systems several feet below the surface have greatly increased the flow of waste through the soil. The effluent from the tile systems has been found to be low in BOD and relatively stable. There are some soils, however, that are difficult to drain. Therefore, a thorough analysis should be made before drainage is undertaken.

9. In cold areas, serious consideration should be given to alternate methods of disposal during the winter period.

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TREATMENT OF INDUSTRIAL PROCESS WASTES AT CHRYSLER CORPORATION *

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Chrysler Corporation has 80 plants in operation in United States and Canada. Among these plants the limits on the composition of industrial process wastes that can be discharged vary over a wide range depending on the location of the plant and the nature of the receiving waterways. The receiving waterways vary from a large sewer system or a river with a high dilution factor to a small creek which, in the dry summer months, may owe its entire flow to the plant effluent. In its cooperative association with state and city authorities on waste disposal problems, Chrysler Corporation has followed the policy that good citizenship requires that the best available techniques be used to avoid pollution of public waterways.

The industrial process wastes produced at these plants include (a) chromic acid from plating processes and from the final rinse of the prepaint phosphating operation; (b) cleaners, spent pickle acids, and rinse waters containing cyanide from plating operations, and (c) the oily wastes originating from machining operations.

Plating Wastes

There is very little electroplating done in these 80 plants. However, even a small chromium or cyanide zinc plating installation can, under conditions of low dilution rates, seriously pollute a plant effluent. Before spending the money for the equipment necessary to treat these cyanide wastes, the necessity for the continued use of each installation was critically evaluated. In some instances, it was found possible to fabricate the part in question from zinc-coated stock. In other cases, it was feasible to substitute a phosphate coating for zinc plating. A study is currently being made of the possibilities of barrel zinc plating from a non-cyanide solution, e.g. pyrophosphate.

Cyanide Treatment

Where plating in the plant was deemed necessary, suitable waste disposal equipment was recommended. An example includes the facilities designed to treat the wastes from a small plating room recently installed at the Chrysler Detroit Tank Plant. Chrome, copper, cadmium, and brass plating as well as zinc and manganese phosphating are done in this plating room. The flow of the water in the rinse solutions is automatically controlled at a rate sufficient to maintain adequate rinse cleanliness without excessive water usage. This is accomplished by means of a conductivity actuated valve. Curbing, of sufficient height to hold the combined volume of 80 per cent of the tanks, was installed to enclose the plating area. Access to the drain of material accidentally spilled or introduced through leakage was prevented by installing the sewer inlet, to which non-polluted rinse waters are led, at a height above the top of the curb. Rinse waters which are permitted to go di-

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rectly to the drain by the City of Warren and the Michigan Water Resources Commission are those following electrolytic alkaline cleaning and those following dilute acid dipping. The overflow and drain from the cleaner tanks and the rinses following any cyanide plating tank were piped to a 720-gal sump tank beneath floor level in the plating room. Two 20-gpm pumps were installed in the sump. These are actuated by a float valve, alternating the use of each pump and transferring the contents of the sump to one of two cyanide treatment tanks. These tanks, located in a separate building, are each of sufficient size to allow a retention time of two hours. After treating with sodium hypochlorite solution and agitating for approximately 30 min, the solutions are tested for the presence of free chlorine and allowed to settle for the hour and a half remaining time. The clear, treated effluent is then drained to the city sewer. The settled sludge is retained since the drain outlet is placed approximately one foot above the tank floor.

Chromium Treatment

The overflow rinses following chromium plating are similarly led to another sump in the plating room. The used acid dip solutions are also led to this sump for disposal. These wastes are periodically pumped to one of another set of tanks for batch treatment of the hexavalent chromium as follows:

1. Adjust the pH of the solution to approximately 2 using sulfuric acid.
2. Add sodium metabisulfite powder in sufficient quantity to change the color of the solution from yellow to green.
3. Adjust the pH of the solution from 8.0 to 8.5 to precipitate the chromium as chromic hydroxide.
4. Settle for two hours after which the clear, treated effluent is emptied to the sewer outlet. The precipitated chromic hydroxide is retained in the tank since the outlet to the sewer is a foot above the bottom of the tank.

Oily Wastes

Oily wastes present probably the most serious disposal problem of any type of waste material resulting from these manufacturing operations. Whenever a plant in existence is confronted with wastes of this nature, every effort is made to (a) reduce the amount of wastes produced, and (b) to concentrate these wastes to the smallest possible volume.

Central systems for coolants have been used for some time to keep the coolant free of metallic particles and to provide sufficient aeration to prevent bacterial decomposition of soluble oil. The central coolant system is capable of operating with sufficient effectiveness to make the disposal of the coolants unnecessary, additions being made to maintain adequate volume of coolant. Where small individual units are in operation, accumulation of fine machining particles will necessitate periodic disposal of the coolant. If adequate dilution is not available, a treatment plant will have to be considered. The use of phenolic additives in cutting oils is usually not necessary.

Some experimental work is in progress to determine the value of filtering alkali cleaning solutions. There has been some encouragement by preliminary plant trials in which part or all of the volume of sprayed cleaner is continuously passed through a filter before returning to the reservoir. The gravity or pressure type filter retains some of the floating oils and greases, and most of the metallic particles, and thus prolongs the life of the cleaner. The increase in cleaner life has varied from two to eight times that of an unfiltered cleaner, depending on the application.

Disposal of certain types of waste such as cyanide pot skim, caustic de-

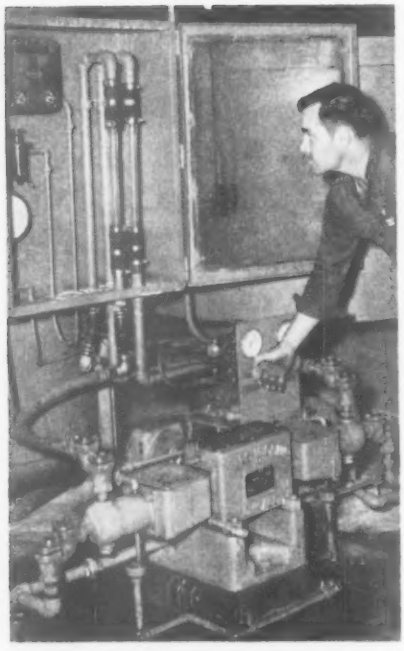

FIGURE 1.—Controls for chemical feed pumps used in flotation treatment.

scaling sludge, and alkali paint strippers containing phenols is often most economically handled by having the wastes hauled by a company which can readily dispose of such materials. Large volumes of such waste would warrant installation of treatment equipment. However, in the case of wastes containing phenols, no completely satisfactory methods for properly destroying this pollutant are available.

Because of the difficulty of completely destroying phenols and because a trace of the order of a few parts per billion, are generally objectionable in a waste effluent, a vigorous campaign is constantly in progress to completely eliminate their use. Substantial progress has been made in eliminating phenolic germicides in soluble oils. Experience has indicated that good maintenance practice allows the use of non-phenol containing oils in both central systems and individual machine systems. After several years of operation, a 60,000-gal central system, in which a non-phenolic soluble oil was used, showed no significant difference in emulsion life or odor as compared with other similar systems in which phenolic containing coolants were used.

Concentration

Use of any of the methods for concentration of the wastes before disposal

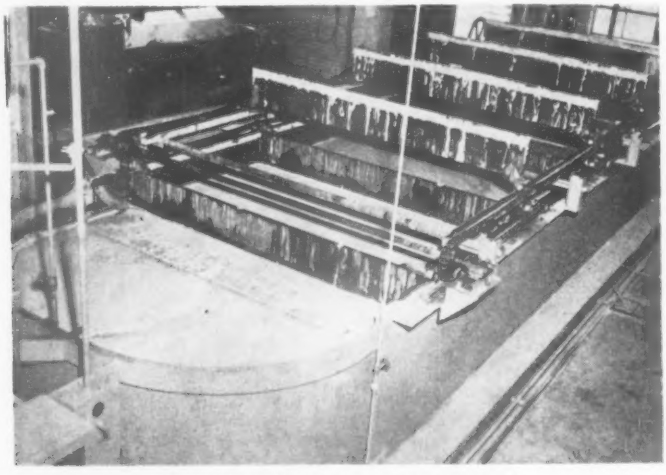

FIGURE 2.—Intake end of flotation unit.

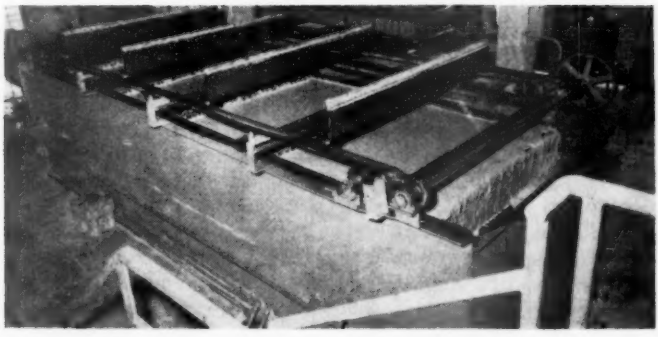

FIGURE 3.—Discharge end of flotation unit showing sludge trough.

to the treatment plant is recommended. Aside from savings due to reduced water consumption, it is often cheaper to treat a given tonnage of waste when concentrated than when diluted with water and other wastes. Unpolluted water should generally be reused and the practice of constant overflow of cleaner solutions should be carefully evaluated. Usually, it is found that overflowing the cleaner solution every four hours is adequate.

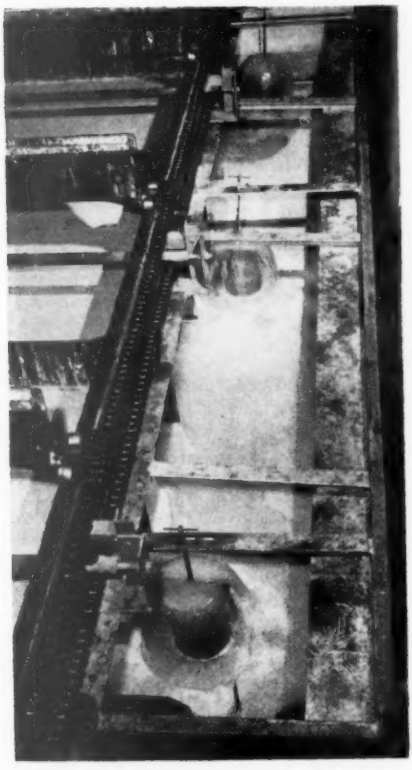

FIGURE 4.—Effluent channel of flotation unit showing treated waste overflows.

Typical Flotation Unit

Chrysler Corporation has several installations for treating industrial process wastes. Usually, the flotation principle is employed, although sedimentation lagoons are also used. The description of a typical flotation unit follows.

The treatment unit is housed in a single building, 54 by 50 ft. Below floor level, a 10,000-gal influent sump, a 100,000-gal holding tank, a 15,000-gal sludge tank, and a 1,500-gal reclaim oil tank are located. The flotation unit, together with the chemical mixing tanks, retention tank, and filter press are on the main floor level.

Figure 1 shows the control valves to the chemical feed pumps. Caustic soda solution is pumped through one line and a mixture of alum and sulfuric acid is pumped through the other line. The concentration of caustic is approximately 1 oz/gal and the concentration of the aluminum sulfate is approximately 2 oz/gal. The reaction of the aluminum sulfate and the caustic soda

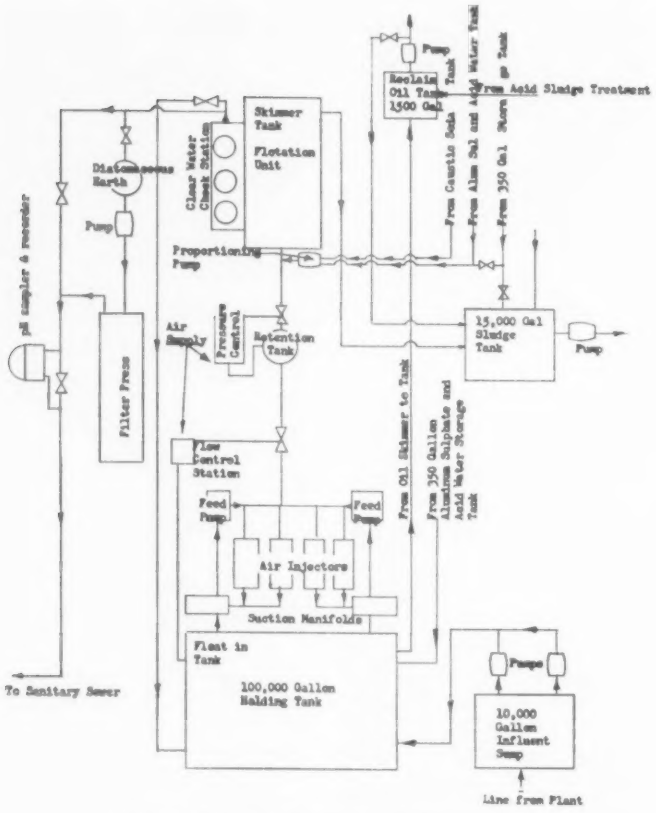

FIGURE 5.—Flow diagram of flotation unit.

produces the aluminum hydroxide floc to which the oil droplets adhere. In the left background is seen the air retention tank which is of sufficient capacity to hold the solution in contact with air at 35 psi for 3 min. A baffle plate is placed vertically in the tank so that all solution is in contact with the air for the full treatment time.

Figure 2 shows what happens when the pressure on the solution is reduced from 35 psi to atmospheric pressure. The air representing the difference in solubility at the two pressures is released as minute bubbles. These bubbles become attached to the particles of floc with the adsorbed oil and cause the combination to rise to the surface. The accumulated mixture of grease, air, floc, and some water is continuously swept into a trough (Figure 3) from which it empties into a sump below the floor.

Figure 4 shows the discharge of the clear water from the bottom of the tank. This water can be checked frequently for pH and visually for remaining floc. The presence of any large quantity of floc is indicative of incomplete removal of oil, since the floc always contains some adsorbed oil. A condition of this sort often can be alleviated by accelerating the rate at which the sweep operates.

Figure 5 shows a schematic flow diagram of the flotation unit with the auxiliary equipment. The aluminum sulfate and sulfuric acid mixture and the caustic soda are added at the same point. Either or both of these chemicals could be added prior to the retention tank. A recent modification of the system makes it possible to take wastewater directly from the influent sump during periods of cleanout of the holding tank.

During the early operation of the treatment plant, the sludge from the flotation unit was hauled away at a cost of one cent per gallon. Since the volume of sludge was very high (200,000 gal per month) and consisted of water and emulsified oil as well as free oil, some work was done to recover the oil by hot acid treatment of the sludge. It was found that if a small amount of sulfuric acid was added and the temperature raised to 160°F a good break of the oil was obtained. In operation, four gallons of sulfuric acid per thousand gallons of sludge will break the sludge in one-half hour at 160°F.

Figure 6 shows the acid cooker. The separated oil is temporarily stored in a reclaimed oil tank before being sold. Approximately $2,000 a month is saved by eliminating the hauling of untreated sludge.

All of the flotation units in Chrysler Corporation plants use aluminum sulfate and caustic soda to break and float the oil. The sedimentation lagoons use ferric chloride or sulfate, the hydroxide floc being formed with either caustic soda or lime.

Experimental Gas Scrubber

The equipment and the chemical procedures just discussed are conventional and in general use throughout the industry. However, a rather interesting departure from the generally accepted procedures took place in an experimental trial at one of the plants. The principle on which the experiment was based was that since flue gas is acidic and contains sulfur dioxide, it should be capable of lowering the pH of a liquid waste. The pH having been lowered, a break of the emulsified oily

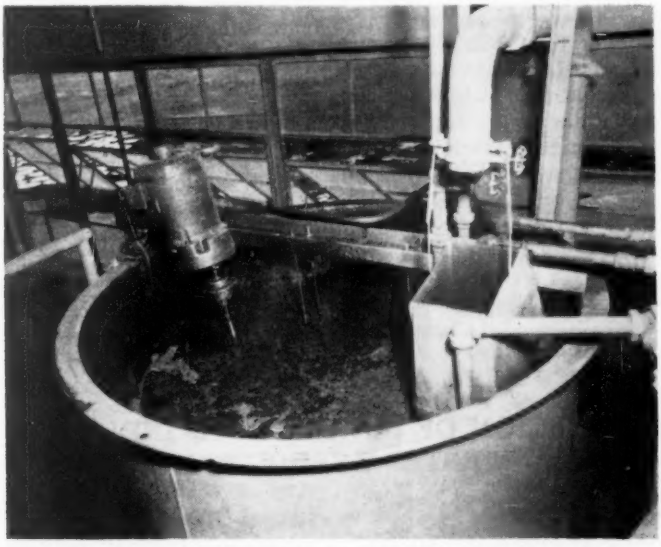

FIGURE 6.—Top view of the hot acid treatment tank used for recovering oil.

wastes was hopefully expected. If incomplete breaking was encountered, a small amount of ferric sulfate was to be added.

A pilot plant gas scrubber was built using wooden slats. The slats were arranged in 15 tiers of 12 slats each. The waste influent was caused to flow by gravity over these slats at a rate of 1 gpm while the flue gas was introduced at the bottom at the rate of 100 cfm. On reaching the bottom of the first cell which was five feet in height, the solution is pumped to the top of the second cell, in which the flue gas from cell one is again in contact. A third cell repeats the process once more, it being the third pass for waste influent and flue gas.

Samples were taken of the process waste influent; the process waste after one, two, and three passes through the scrubber; and with 137 mg/l of ferric sulfate added to the solution after three passes through the scrubber. The pH, suspended solids, grease, and chlorine demand were determined in these samples. The pH was reduced from 10.8 in the influent to 5.0 after the third pass. Suspended solids were reduced from 3,460 mg/l in the influent to 620 mg/l after the third pass. Grease was reduced from 1,880 mg/l in the influent to 180 mg/l after the third pass. The addition of ferric sulfate to the solution after scrubbing further reduced the amount of suspended solids but had no significant effect on the amount of grease present. Up to this point, the procedure was promising, especially since, on adjusting the pH to eight with lime, the grease was reduced to approximately 30 mg/l. However, the chlorine demand of the samples increased from 10 mg/l in the influent to 1,900 mg/l in the scrubbed waste solution. The odor of sulfur dioxide was very pronounced in this latter sample. It was found in some preliminary trials that bubbling air through the solution for 1½ hr reduced the chlorine demand from 1,900 to 550 mg/l. Since (a) it was evident at this point that the equipment required for treating wastes by this process would be at least as expensive as the necessary equipment for a sedimentation or flotation process, and (b) the chances of economically reducing the sulfur dioxide concentration to some acceptable level were not readily apparent, no further work was done on this program. This investigation is reported in the hope that some time may be saved by others.

Summary

A problem constantly encountered by waste disposal engineers is to choose the method of treatment which will produce an effluent with the least possible objectionable matter. It is simply good manners to attempt to return water to the waterways in as nearly the same condition as it was received. Although continual progress is being made, much work remains to develop the techniques to make this a reality.

32nd ANNUAL MEETING

FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Dallas, Texas — *October, 12-15, 1959*

STATLER HILTON HOTEL — **DALLAS MEMORIAL AUDITORIUM**

DESIGN AND TREATMENT OF METAL PROCESSING WASTEWATERS *

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The Conneaut Base Plant of the General Electric Company has been in operation since 1941. The products manufactured are incandescent, photoflash, automotive sealed beam headlight, and fluorescent lamp bases of various sizes and shapes. The manufacturing operations include progressive dieset operation for stamping and drawing metal parts, glass and plastic molding, a bright dip operation, and inspection. Some of the raw materials purchased include aluminum, brass, nickel, iron, and steel strip; glass manufacturing ingredients; plastic powders, acids; soaps, and soluble oils. Practically the entire plant is in operation 24 hr a day, 5 days a week, and has a peak employment of just under 200 people.

Except for a brief trial with the use of a limestone bed for attempted neutralization of metal-bearing acid wastes, the plant's industrial waste load has, until this year, been discharged without treatment directly into the municipal sewer system. This system discharged directly into Lake Erie without treatment.

After the passage of the Ohio Water Pollution Control Act in 1951, the City of Conneaut received notice to modernize its sewage collection system and build and put into operation necessary treatment facilities. This project was completed in 1957.

While the municipal plant was in the planning stage, a city ordinance was passed which covered the discharge of industrial wastes into the new city sewer system. A part of this ordinance set the specifications for the acceptance of acids, suspended solids, oils, and metal ions. These specifications are summarized in Table I. Later discussion will emphasize the fact that pH, copper, zinc, and soluble oil acceptable concentrations are of greatest concern.

Acid wastes from the Conneaut plant have their origin in an automatic bright dip process which is used for finishing all the plant's production. Soluble oil wastes are generated during the metal stamping and drawing operations in the press room.

Each month in manufacturing operations, the plant consumes 40,000 to 50,000 lb of mixed acid (71.9-per cent H_2SO_4 and 19.1-per cent HNO_3) and 1,000 gal of soluble oil. About 1.5 mil gal of water are used during this same period.

Problem

After a preliminary survey of the manufacturing processes had been completed and it was definite that a waste

TABLE I.—Portion of City of Conneaut Ordinance Showing Extreme Limits for Acceptance of Industrial Waste Materials in Sewage Handling System

Item	Max Continuous Limit
pH	5.5 to 9.5
Soluble oil (mg/l)	50
Iron (mg/l)	15
Copper (mg/l)	3
Zinc (mg/l)	2
Chromium (mg/l)	5

* Presented at the 31st Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Detroit, Mich.; Oct. 6–9, 1958.

load existed, and after consultation with the company's specialists, the following program of action was outlined in order to define and solve the problem:

1. The completion of a study of the sources of wastes and the taking of all economical steps short of treatment to reduce or eliminate the pollution load.
2. The completion of a detailed definition survey to determine the quantity and characteristics of the wastes.
3. The carrying out of laboratory and pilot scale operations to crystallize the best treatment approach.
4. The design, construction, and placing into operation of the necessary treatment facilities to solve the remaining problem.

Some reductions were realized in the magnitude of the waste load originating in the bright dip process through improvement in housekeeping, changes in manufacturing operations, and process piping changes. The soluble oil load was reduced by approximately 35 per cent through changes in methods of application within the diesets.

After all possible in-plant steps had been taken to reduce the load, the definition survey was undertaken to determine the wastes' magnitude, both as to volume and composition. The survey, made by plant personnel, covered one shift for one production week. Samples of waste effluent were taken every 15 min, 8 hr per day for 5 consecutive days. The individual samples were then separated into hourly, daily, and weekly composites prior to analysis. The hourly composites were checked for pH; the daily composites for pH, acidity or alkalinity, aluminum, copper, zinc, iron, and oil; and the weekly composites for total and suspended solids. The volume of the metal-bearing acid waste discharge amounted to 2,750 to 3,000 gph and the characteristics are shown in Table II.

TABLE II.—Metal-Bearing Acid Waste Characteristics

Day	pH	Cu (mg/l)	Zn (mg/l)	Al (mg/l)	Fe (mg/l)	Suspended Solids Total (mg/l)
1st	1.28	331	83	3.4	0.65	—
2nd	1.27	336	55	1.8	0.75	—
3rd	1.20	385	54	1.8	0.70	—
4th	1.26	204	83	2.2	0.70	—
5th	1.30	370	120	2.2	0.60	214*

* Weekly composite.

Shortly after the survey was completed, a high percentage of the plant's output was converted from brass to aluminum. A second survey was necessary to determine if the characteristics of the waste load had been affected, but this showed that no change had taken place.

Survey activities to define the magnitude of the soluble oil load indicated that the effluent from the stamping and drawing operations had an average pH of 9.1 and an oil concentration of 8,070 mg/l.

As the first step in phase 3, neutralization experiments were undertaken to determine methods of treatment and to observe the reactions and results obtained with the use of different chemical ingredients. Laboratory investigations were undertaken at the Conneaut plant, the Erie General Electric Company plant, the Lamp Division's Chemical Products Plant, and by various equipment manufacturers and suppliers of soluble oil. After this work had indicated that the wastes could be treated satisfactorily in small quantities, the next step was pilot scale studies.

Since the laboratory work had demonstrated that neutralization of the wastes produced a finely divided sludge which was difficult to filter, it became apparent that precoat filtration would probably be necessary in the final treatment plant. To test this approach, two pilot filters were procured and tested. The first tried was a rotary drum pre-

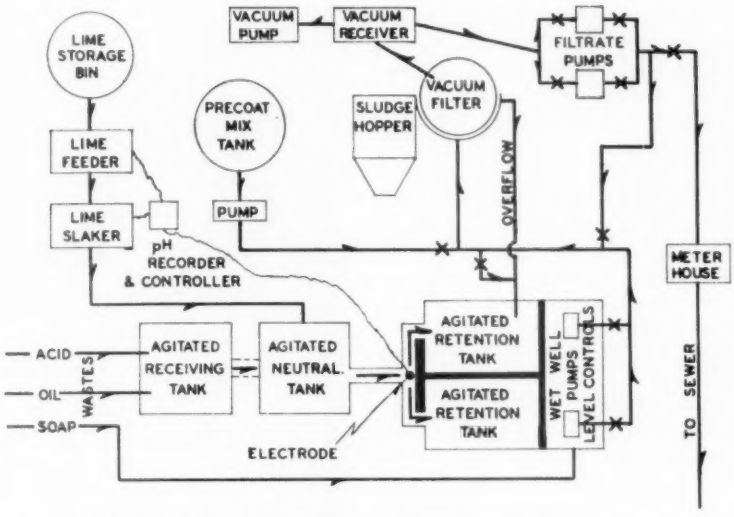

FIGURE 1.—Flow diagram for wastewater treatment process.

coat vacuum unit. This unit delivered a satisfactory effluent if the wastes were given 1½ hr of reaction and mixing time before filtration. The second filter tested was a pressure precoat type. This filter blinded very quickly once filtration was started; therefore, it was judged unsatisfactory and was rejected.

FIGURE 2.—Wastewater treatment building and lime storage silo.

During the pilot scale stage, the soluble oil wastes were mixed in varying concentrations with the acid wastes before the addition of lime slurry. This work showed that the oil emulsion could be broken and removed by this procedure. Laboratory analyses also indicated that the effluent from the pilot unit met the ordinance requirements in every respect.

The pilot plant work further demonstrated that either continuous or batch treatment could be used in solving this problem. Preliminary design also indicated that the treatment facilities using either approach would be comparable in cost.

Treatment Plant

General Description

The continuous treatment process incorporated in the waste treatment plant is shown in the flow diagram, Figure 1. The treatment building is shown in Figure 2. Acid wastes, which make up about 80 per cent of the total influent,

flow directly from the manufacturing process to the receiving tank in the treatment plant. This tank is used primarily for mixing the acid wastes with spent soluble oils which are periodically pumped in. From the receiving tank, the contents flow into the duplicate reaction tank where the lime slurry is added. Automatic control of the lime addition is obtained through continuous pH measurement of the discharge from this tank. A recorder-controller, actuated by the pH measurement, operates the lime feeder and slaker.

The treated wastes then flow into the retention stage for a 1½- to 2-hr mixing time and then over a weir into the wet well which serves as the collection basin from which these wastes are pumped to the filter. Concentrated soap wastes which require only filtration are also discharged directly into the wet well without previous treatment. The final treatment operation is the vacuum filtration, from which the filtrate is pumped to the city sewer. However, before the effluent leaves the plant property, it passes through the Parshall flume at the meter house where the pH and flow are measured and composite sampling is routinely done.

Equipment on Second Floor

Mounted on the roof of the building housing the treatment facilities and extending through into the second floor area is an 80-ton capacity lime storage bin complete with a 7-ton/hr pneumatic unloading system for use in transfer of lime from railroad hopper cars to the bin.

On the second floor directly under the bin is a 500-lb/hr capacity volumetric type lime feeder which gravity feeds a continuous lime slaker, Figure 3. This unit has a slaking capacity of 500 lb/hr of quick lime with a 4 : 1 water-lime ratio and a 30-min retention period.

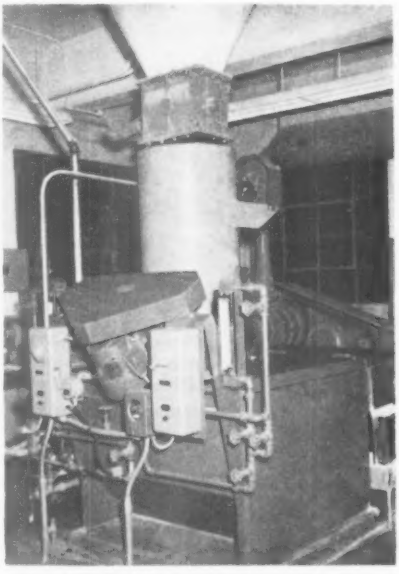

FIGURE 3.—Lime feeder and slaker arrangement.

The filtration installation located on the second floor consists of a rotary 150 sq ft filter area drum-type precoat vacuum filter (Figure 4) with a 6-ft diameter drum equipped with a variable speed automatic advance knife blade and a sludge storage hopper.

The auxiliary equipment for the filter consists of a vacuum receiver, a

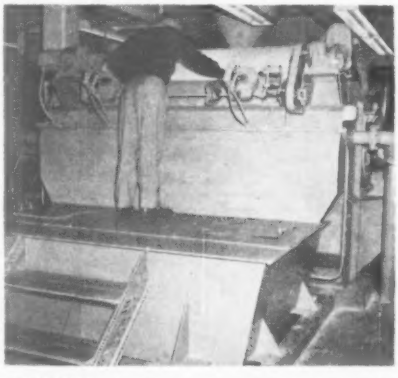

FIGURE 4.—Precoat vacuum filter and sludge hopper.

rotary wet type vacuum pump with a 40 hp motor, and a sealing water tank.

Also on this floor is the motor control center, a laboratory area, pH recorders, lime feed controllers, and a vacuum pump used for unloading the lime from railroad cars.

Equipment on First Floor

The first floor is divided into three sections; the reaction tank room, the precoat mix room, and the garage.

In the reaction tank room there are five acid brick-lined open top tanks which extend from floor level to a depth of 12 ft. All tanks have a liquid depth of about 7 ft. Two tanks are approximately 3 ft square and have a capacity of 470 gal. Each is equipped with a vertical type flash mixer and they are interconnected at the bottom with an 8-in. square opening. Two larger tanks, with capacities of about 4,400 gal, are used as retention tanks to permit added reaction time. These tanks can be used separately or simultaneously depending on the volume being processed. Each is equipped with a walking beam drive flocculator complete with inverted V-trough paddle assemblies which operate at a maximum speed of two strokes per minute. The purpose of the flocculators is to prevent solution channeling through the tanks.

The fifth tank is the wet well and contains two submerged, variable speed wet well pumps which are used to deliver the neutralized wastes to the vacuum filter. The maximum capacity of each of these centrifugal pumps is 75 gpm operating at a total head of 35 ft. Float level controls govern their output to keep the solution level within specified limits and a high level alarm will warn the operator of malfunctioning of the unit.

The precoat room contains a 6-ft diameter by 6-ft high, open top steel tank equipped with a flash mixer. This tank is used to prepare the precoat slurry for the vacuum filter. The precoat slurry pump is a variable speed diaphragm type with a capacity of 48 gpm at a 40-ft head.

Two 85-gpm filtrate pumps located in this room pump the filtered effluent from the vacuum receiver to the sewer and are also used during the precoating cycle.

The sludge hopper attached to the vacuum filter extends through the ceiling of the garage and is equipped with a bottom discharge gate for loading the sludge by gravity into a dump truck.

The meter house, located about 600 ft from the treatment building, contains a Parshall flume, sample gathering equipment, flow meter, and pH electrodes.

TABLE III.—Waste Treatment Installation Costs

Item	Cost ($)	Per Cent of Total
Treatment building	121,300	44.0
Meter building	3,400	1.2
Utilities	11,600	4.1
Installed equipment	107,200	39.0
Design costs*	28,000	10.1
Miscellaneous	4,500	1.6
Total	276,000	100.0

* Includes fees to engineering firm, costs charged to General Electric plant engineering, and to General Electric consulting personnel.

Installation Costs

The installation costs of the waste treatment facilities totaled approximately $276,000. A breakdown of this total expenditure has been summarized in Table III. The treatment building costs, totaling 44 per cent of the overall expenditure, represents the largest cost item. The filtering equipment, which cost $30,000 or 10.9 per cent of the total, was the highest individual equipment expenditure. Only one other expenditure exceeded 10 per cent of the total cost, design and engineering costs amounted to $28,000 or 10.1 per cent of the total cost.

Performance

Operations in the treatment plant were started on a continuous basis in February 1958. Although designed to provide 24-hr waste treatment, the present load, due to reduced production demands, is treated in 16 hr/day. This necessitates an 8-hr standby period. One operator per shift is still required over the 24-hr period. Each operator is responsible for maintaining an acceptable effluent to the city sewer and makes routine process checks to insure proper treatment. Continuous pH recordings of both the "in process" wastes and the effluent being discharged into the city sewers keep the operators informed of any unusual changes.

An evaluation of the effluent indicates that the treatment plant is doing a completely satisfactory job. Table IV summarizes the daily effluent analysis for the month of August.

With the exception of the zinc concentration, all metal concentrations are within the allowable limits specified by the city ordinance. The average zinc concentration of the effluent is slightly less than 1 mg/l and thus well within the 2 mg/l limit. Occasionally, however, the zinc concentration falls outside the limits set in the ordinance. It is felt this apparent high concentration is of no great consequence because it may be caused by some substance interfering in the zinc determination. A safety factor is present since the treatment effluent is diluted in the city sewer system by all the remainder of the plant discharge.

TABLE IV.—Effluent Analysis for August 1958

Determination	Average	Max	Min
pH	7.5	10.6	6.8
Copper (mg/l)	0.5	2.5	<0.5
Zinc (mg/l)	<1.0	5.4	<1.0
Chromium (mg/l)	<1.0	—	—
Iron (mg/l)	<1.0	—	—
Aluminum (mg/l)	<1.0	—	—
Susp. solids (mg/l)	166	411	40
Soluble oils (mg/l)	—*	—	—

* None detected.

TABLE V.—Waste Load from Two-Shift Operation in August 1958

Waste Type	Avg Volume (gpd)	Per Cent of Total Volume
Acid	17,100	56.8
Soap	3,800	12.6
Oil	1,000	3.3
Process (slaker)	7,000	23.3
Misc. (vac. pump)	1,200	4.0
Total vol. processed	30,100	100.0
Sludge equivalent	900	3.0
Measured effluent	29,200	97.0

The daily waste load being handled through the plant is given in Table V. The average total waste treated is 29,200 gpd which represents a treatment rate slightly over 30 gpm. However, rates above 100 gpm have been satisfactorily maintained by the system without trouble. The metal-bearing acid wastes which total 17,100 gpd require an average of 56 lb of lime per 1,000 gal treated. This value compares favorably with the theoretical or laboratory results which indicated from 50 to 54 lb per 1,000 gal of acid wastes would be needed.

Operating Costs

A summary of the operating costs of the treatment plant are shown in Table VI. These costs currently total $3,793 per million gallons of waste treated.

TABLE VI.—Operating Costs for Two-Shift Operation *

Item	Cost ($/mil gal)	Per Cent of Total
Agitation	60	1.5
Neutralization	360	9.5
Filtration	913	24.1
Sludge removal	280	7.4
Manpower	2,135	56.3
Miscellaneous	45	1.2
Total	3,793	100.0

* No depreciation included.

This cost, particularly when compared with domestic wastewater treatment, is high as a result of the low volume of wastes being treated at the present time. For instance, by extending operations to include the third shift, the treatment costs would be reduced to $2,490 per million gallons. It is also of interest to note that the plant can probably handle close to 100 gpm. Further reduction is still possible with flows approaching the designed capacity of the system.

Table VI shows the filtration costs to be $913 per million gallons or 24.1 per cent of the total treatment costs. Of this $913, the precoat material costs $545, or close to 60 per cent of the total filtration costs. Each week an average of 900 lb of precoat material at a cost of $80 is used. Since ample spare filtration capacity is available, increased waste loads will not materially affect this value and the unit cost of treatment will drop in direct proportion to the added volume processed.

Operating Experiences and Modifications

Problems not originally anticipated, no doubt, appear in all treatment plants during the early periods of operation. In this respect, the Conneaut plant is no exception. Some of these problems and the changes made to correct them are outlined for the benefit of others faced with a similar situation.

Water Supply Pressure

One problem was extensive pressure fluctuations in the treatment plant water line. These fluctuations interfered with obtaining a uniform water to lime feed ratio in the slaker. In addition, the solenoid water control valve on the slaker failed to close at periods when low pressures were observed. As a result, constant attention was needed to keep the process in control.

This condition was corrected by designing and installing a separate pressurized system for all process water as

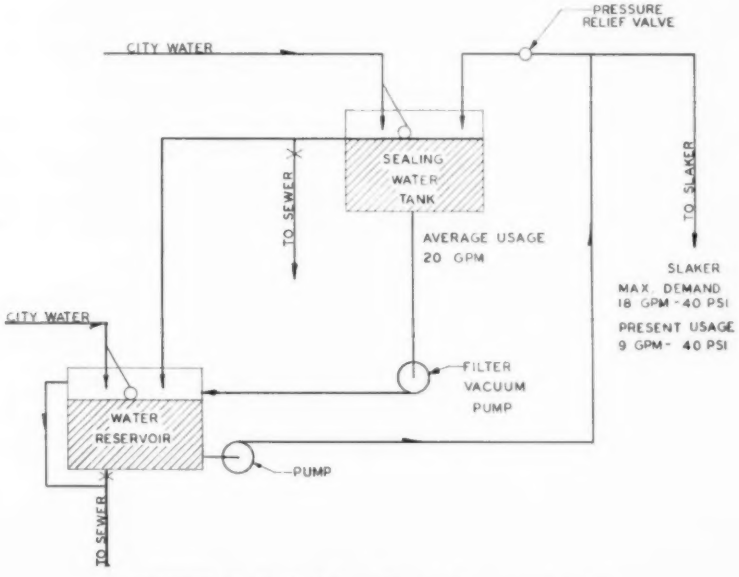

FIGURE 5.—Revised flow diagram for process water.

shown in Figure 5. Key components in the system center around the water reservoir, the pump, and the pressure relief valve. The proper pressure is maintained at the slaker by regulation of a 1½-in. pressure relief valve. The water is continuously circulated through the vacuum pump until required by a demand at the slaker. Make-up city water is then added at either reservoir through the float controls, depending on where the deficiency is first experienced. During normal operation, the water demand required by the slaker permits sufficient cold make-up water to maintain the proper temperature balance through the system. During periods, however, when the slaking operation is down, a small bleed-off to the sewer through either sewer outlet is needed to balance the temperature requirements at the vacuum pump. Previous design requirements in this area designated separate fresh water feeds to both pieces of equipment with the cooling water to the vacuum pump going directly to the sewer. As a result of the improved utilization of water, the cost of operating the new system is offset to a large extent.

pH Control

When the plant was first started, unusual process pH variations were also experienced with the automatic lime feed system. Continuous over- and under-shooting of the control instrument produced a pH measurement ranging from 2 to 3 units about the control point.

With this broad pH range, automatic control of the process was not practical. The trouble was found to stem from improper location of the pH electrodes which resulted in too short an elapsed time interval between the start of neutralization and the point of pH measurement. Once this point of measurement was relocated to permit added reaction time and a blending of the reacted slurry, a definite improvement in control was obtained.

Sludge Buildup

After several weeks' operation, it was found that a gradual buildup of sludge was developing in the retention tank. The agitation provided by the flocculators was not sufficient to keep the calcium sulfate sludge in suspension. Once the buildup reached a point above the flocculator paddles and reduced their effectiveness, additional settling proceeded rapidly until the retention tank was nearly full of sludge.

During the sludge buildup period, tank capacity was in effect progressively reduced until the waste stream was flowing across the surface with practically no retention time. At this point it was necessary to discontinue treatment operations in order to clean the tank. Various baffles and agitation methods were tried during the second attempt to operate the plant, but the tank still filled with sludge in about five days. The method finally developed to keep the sludge in suspension was to introduce air agitation at the base of the flocculator paddles and to install a 34-in. stirring blade in the center of the tank. During five months of operation with these improvements there has been complete elimination of the sludge buildup problem.

However, it is felt that the present method of agitation is not the most economical available. A study is underway to find a sounder method of agitation with an economical installation and operating cost.

Lime Supply

In an attempt to reduce the amount of calcium sulfate sludge being developed with the use of high calcium lime, a trial of dolomitic lime was made over a two-week period. According to an hourly settling test comparison, a 20 to 30 per cent reduction in the volume of sludge was indicated while using the dolomitic lime. Dolomitic lime also offered a small savings (approximately $3.00/ton) over the high

calcium lime. Disadvantages experienced due primarily to equipment limitations, however, appeared to outweigh the advantages gained. For this reason the use of dolomitic lime was discontinued with no future trials contemplated.

Sludge Feed to Filter

Finally, a problem caused by the installation of one master feed pipe to the filter has developed since the start of operation. Sludge has accumulated in the intermittently used vertical pipes feeding into the master feed line. During normal operation, only one line out of a possible five supply lines is used for filtration. This allows sludge to settle in and finally plug the four lines not in use.

Conclusions

As a result of six years of preliminary planning and a period of about five months of actual waste treatment, the following conclusions are drawn:

1. In building and operating the Conneaut treatment plant, the intended objective was accomplished—that of discharging a plant effluent which meets the requirements specified in the city ordinance. Five months of operation attests to the plant's ability to meet such requirements.

2. The treatment of metal processing wastes is expensive. An investment of $276,000 in plant and equipment and an anticipated annual operating cost of $27,000 bears this out.

3. The high non-productive cost to industry for waste treatment facilities emphasizes the need for realistic specifications in industrial waste ordinances to avoid unnecessary expenditures for separate treatment facilities if satisfactory combined treatment can be accomplished.

4. The definition survey as a preliminary step was quite important in delineating the exact type and nature of the problem prior to design of the treatment plant.

5. The pilot scale treatment work was also an important step in establishing the treatment process and the type of filtration to be used.

6. The definition survey and the pilot plant worked together to reduce the final cost of the treatment facilities. It was originally estimated several years earlier that such facilities would have a cost of more than $300,000.

Acknowledgments

K. S. Watson, Water Management and Waste Control Consultant for the General Electric Company, was responsible for much of the basic planning of the project.

Havens and Emerson, of Cleveland and New York, designed the wastewater treatment facilities.

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Stream Pollution

EXPERIMENTS ON THE DISSOLVED OXYGEN REQUIREMENTS OF COLD-WATER FISHES *

By Robert C. Davison,†‡ Wilbur P. Breese,† Charles E. Warren,† and Peter Doudoroff §

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The dissolved oxygen requirements of the salmonids have been investigated more thoroughly than those of any other group of fishes, but specific knowledge of these requirements is still quite limited. The level to which these fishes can reduce the dissolved oxygen content of water when confined in sealed vessels, before dying, or losing equilibrium, sometimes has been determined as a measure or lower limit of their tolerance (1). Several investigators have exposed the experimental animals to more or less constant low oxygen concentrations, achieved and maintained in various ways (2) (3) (4) (5) (6). Minimum concentrations tolerated by resting fish for one day or longer have been evaluated in this manner.

In order to succeed in their natural environment, fishes must be able not only to tolerate the most adverse conditions to which they may be occasionally exposed for short periods, but also to maintain at other times normal activity—resisting currents, seeking food, and escaping enemies. They must grow and be able to reproduce successfully. Dissolved oxygen concentrations necessary for the maintenance of varied, healthy fish populations probably are much higher than the concentrations which barely can be tolerated for limited periods by resting fish even of the most sensitive kinds. Field studies of fish distribution in relation to dissolved oxygen, especially in polluted waters (7) (8), as well as some experimental data and theoretical considerations have led to this conclusion.

Observations made in the field are not sufficiently instructive, however, and the validity of conclusions concerning minimum oxygen levels necessary for the maintenance of normal fish populations can be seriously questioned as long as these conclusions are based mostly on such observations. It is not clear to what extent the absence or scarcity of desirable fishes in many waters polluted with oxygen-depleting organic wastes is due to dissolved oxygen deficiency. The lack of fishes may be referable often to other pollutional effects of these wastes, which can upset the ecology of receiving waters in various ways, as by stimulating growth of benthic bacterial "slimes" and other periphyton which may interfere with the production of bottom-living fish-food organisms. Furthermore, field studies rarely have provided sufficiently

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complete and accurate information concerning the past history of the fish populations sampled. The observed environmental conditions may not always represent average conditions and are rarely indicative of the most adverse conditions that may have occurred in the past. Besides, fish can move about in response to changing conditions.

A number of experiments have been reported on the influence of reduced oxygen concentrations on the respiratory metabolism, activity, and development of fishes, on the effects of acclimatization and other factors which influence resistance to low oxygen concentrations, and on the avoidance reactions of fishes to oxygen deficiency. Nevertheless, there is still not enough reliable information concerning minimum oxygen concentrations compatible with prolonged survival, normal performance, successful development, and general well-being of fishes. The variations of resistance to oxygen deficiency due to environmental and other factors also need further investigation. Accordingly, a comprehensive cooperative study of the influence of dissolved oxygen on the survival, development, food consumption, growth, activity potential, and movements of fishes has been undertaken. A factual basis will thereby be established for judgment as to the minimal oxygen concentrations that are compatible not only with brief survival of certain fishes, but also with their ordinary activities and their continued prosperity under varying conditions encountered in nature.

In this paper are collected the results of some exploratory work preliminary to the more detailed studies which are to be reported in future publications. From a large accumulation of test results, those data deemed most instructive have been selected and are briefly reported here, though some of the experiments are not considered entirely satisfactory, and some of the findings need verification. Subjects considered here are (a) the influence of temperature on the minimum oxygen concentrations necessary for the survival of fasting juvenile coho salmon, *Oncorhynchus kisutch*, for moderately prolonged exposure periods; (b) the long-term survival, food consumption, and growth of juvenile coho salmon at low oxygen concentrations and moderately high temperatures; (c) the influence of sulfite-process pulp-mill waste, in concentration well above that ordinarily encountered in receiving streams of the Pacific Northwest, on the resistance of coho salmon to oxygen deficiency; and (d) the resistance for periods of one to five days of the sculpin *Cottus perplexus* to low oxygen concentrations at summer temperatures (18 to 19°C).

Material and Methods

Most of the experiments were performed at the Yaquina Bay Fisheries Laboratory of Oregon State College, located near Newport, Ore. The water supply is obtained by filtering the soft water from a small spring-fed stream, which is naturally of high quality.

History and Feeding of Fish

The fish used in most of the experiments were wild juvenile coho salmon, *Oncorhynchus kisutch* (Walbaum), 40 to 109 mm in total length, seined from the headwaters of Beaver Creek in Lincoln County, Ore. Presumably they were all one year old or younger. Freshwater sculpins, *Cottus perplexus* (Gilbert and Evermann), 40 to 67 mm in total length, collected in Oak Creek, Benton County, also were used in one series of experiments.

The fish ordinarily were held for periods of one to eight weeks in outdoor tanks supplied with running water, where they were fed raw liver every other day. Before use in experiments, they were acclimatized for at least four days to a temperature (usually 20°C) differing by not more

than 4°C from the test temperature. Thereafter, the fish were held in the test vessels at the test temperature for 24 hr before the dissolved oxygen content of the water was reduced. They were not fed for one day before being placed in the vessels, nor during the experiments, except during tests of long duration (i.e., more than five days). In a prolonged experiment on the influence of reduced oxygen concentrations on the food consumption and growth of coho salmon, feeding once every two days was continued throughout the tests. One hundred uniform pieces of liver, with a total weight of 5 g, then were dropped, five pieces at a time, into each test vessel containing 10 fish, and the number of pieces consumed by each group of test animals was noted. Unconsumed food was withdrawn by means of a siphon immediately after the feeding, and excrement was removed daily in the same manner.

The experiments on the influence of sulfite waste liquor on the dissolved oxygen requirements of juvenile coho salmon were performed at Corvallis, Ore., using filtered, untreated river water supplied to the laboratory from Marys River. The salmon for these experiments were collected from the headwaters of the Yaquina River, Lincoln County, Ore. In the laboratory stock-tanks they were fed a prepared mixture of ground beef liver and fish, with dried meal supplements.

Apparatus

An apparatus essentially similar to those used is diagrammed in Figure 1. Shown in Figure 1 is one of several units used simultaneously, all receiving water from a common temperature-control and distribution system, which is also pictured. Each unit consists of a test vessel, a glass column in which oxygen is removed from the water by means of nitrogen, and other components. Unlike the column described by Fry (9), each column used for reducing

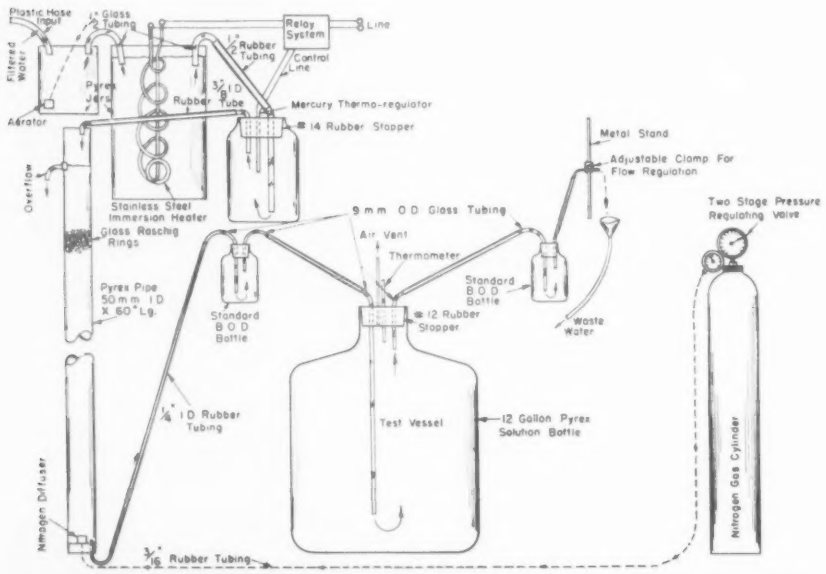

FIGURE 1.—Apparatus used for studies of the effects on fishes of reduced dissolved oxygen concentrations.

the oxygen content of the water is capable of delivering at one time water of only one oxygen concentration, so that a separate column must be used with each test vessel. A single vessel receiving water with dissolved oxygen near the saturation level is provided for performing a control test concurrently with each series of tests at reduced oxygen concentrations.

The vessels in which the fish are held during tests are "Pyrex" glass solution bottles of 5- or 12-gal capacity, fitted with No. 12 rubber stoppers. Inserted into each stopper are an inlet tube (9 mm OD glass tubing) extending nearly to the bottom of the bottle, a screened outlet tube extending about 3 in. into the neck of the bottle, a thin glass tube which serves as an air vent, and a thermometer.

Operation Pattern

The water supplied to the test vessels is filtered and then heated to the desired temperature by means of a thermostatically controlled, stainless steel, tube-type immersion heater suspended in a 10-gal Pyrex glass jar. The water flows into this jar through a connecting siphon from another jar which is always filled to overflowing, so that a constant water level is maintained. The mercury thermoregulator which controls the water temperature is inserted into the rubber stopper of a tightly stoppered wide-mouth glass jar, to which the heated water is delivered through a siphon tube, and from which it is distributed to the glass columns through several other tubes passing through the stopper.

Each of the columns is a vertically placed, 5-ft section of 2-in. Pyrex glass pipe, stoppered at the bottom, filled with Raschig rings, and having an overflow at the top. Water enters the column at the top, at a rate sufficient to keep the column full to overflowing, the small amount of overflow going to waste. Dissolved oxygen is removed from the downward flowing water by passing through it a stream of rising nitrogen bubbles released several inches above the bottom of the column from a gas disperser which is connected to a cylinder of compressed nitrogen. The water leaves the column at the bottom through a tube inserted into the stopper, and flows successively through a sampling bottle (300-ml standard BOD bottle), the test vessel, another sampling bottle, and an adjustable tube discharging into a drain funnel. The discharge tube can be raised or lowered as necessary to adjust the rate of flow through the system.

The water flows through each glass column and test vessel at a uniform rate of 300 ml/min or more. The dissolved oxygen content is adjusted by regulating the flow of nitrogen to each column by means of a two-stage pressure-reducing gas regulator with needle valve. Samples for chemical analysis of the water flowing into and out of each test vessel are obtained by removing the sample bottles, after withdrawing their stoppers, and immediately substituting other sample bottles.

When it was necessary to add waste sulfite liquor continually to the water flowing into a test vessel, the liquor was injected by means of a low-capacity chemical pump into the inlet tube through a glass T located between the influent sample bottle and the test vessel. The influent water thus could be sampled for determination of the dissolved oxygen content before it had been contaminated with the liquor.

Test Procedure and Conditions

Dissolved oxygen concentrations were determined usually by the unmodified Winkler method (10) at the Yaquina Bay laboratory, and by the Alsterberg (azide) modification of the Winkler method (10) at the Corvallis laboratory.

The oxygen content of the water in the experimental vessels was reduced

to the desired levels gradually, during a period of about 6 to 8 hr. The recorded duration of exposure of the test animals to the tested oxygen concentration is in every case necessarily only approximate, as the moment when this concentration was achieved could not be precisely determined, and the fish then had already been exposed for some time to only slightly higher concentrations. The dissolved oxygen content of the effluent from a test vessel, determined several times during the first day of a test and at least twice daily thereafter, was considered to be the concentration to which the test animals in the vessel were exposed at the time of sampling. When the oxygen concentration in the effluent had become nearly stable, it differed by not more than a few tenths of a milligram per liter from the oxygen content of the influent water. In experiments in which the fish were fed in the test vessels, the flow of water through the vessels was interrupted briefly at the time of each feeding. The numbers of fish surviving were noted and recorded at regular intervals, and dead fish were removed promptly. Data were discarded from experiments during which any control fish died in the well-oxygenated water.

Excepting experiments in which sulfite waste liquor was added to Marys River water, the recorded free carbon dioxide concentrations of water leaving the test vessels did not exceed 3.5 mg/l and were usually much lower, and the recorded pH values were between 7.0 and 7.9.

Experimental Results

Influence of Temperature

Some results of tests of the lethality to juvenile coho salmon of low dissolved oxygen concentrations at five different temperatures ranging from about 12 to 23.5°C, all performed in the fall of 1953, are presented in Table I. Five-gallon test vessels were used, with water renewed at the rate of 300 ml/min. The test temperatures did not

TABLE I.—Survival for One Day of Juvenile Coho Salmon at Different Temperatures and Low Dissolved Oxygen Concentrations in Fall

Date (1953)	Temperature (°C)	No. of Tests	No. of Fish	Dissolved Oxygen Concentration (mg/l)			Percentage of Fish Surviving
				Over-all Range	Range of Test Means	Mean of Test Means	
12/13	12	3	30	1.05–1.2	1.12–1.13	1.12	17
12/13	12	2	20	1.3 –1.4	1.35–1.37	1.36	95
11/15	16	2	20	1.05–1.25	1.12–1.18	1.15	50
11/15	16	4	40	1.2 –1.45	1.30–1.35	1.33	90
11/29	16	3	30	1.5 –1.6	1.53–1.60	1.57	100
10/7	20	3	30	1.35–1.45	1.35–1.42	1.39	67
9/28	20	1	10	1.65 only	1.65 only	1.65	100
9/28	20	3	30	1.8 –2.0	1.83–1.90	1.88	100
10/14	22	2	20	1.5 –1.6	1.52–1.55	1.54	85
10/14	22	4	40	1.8 –1.9	1.82–1.87	1.85	100
10/25	23.5	2	20	1.8 –2.0	1.90–1.92	1.91	35*
11/5	23.5	3	30	2.05–2.2	2.12–2.15	2.13	97†

* Percentage surviving after about 16 hr, when the tests were prematurely interrupted.

† The same result (97 per cent survival) was obtained also in 3 tests performed on October 26 with DO means averaging 2.12 mg/l, but ranging widely from 2.03 to 2.23 mg/l (over-all DO range, 1.95 to 2.3 mg/l).

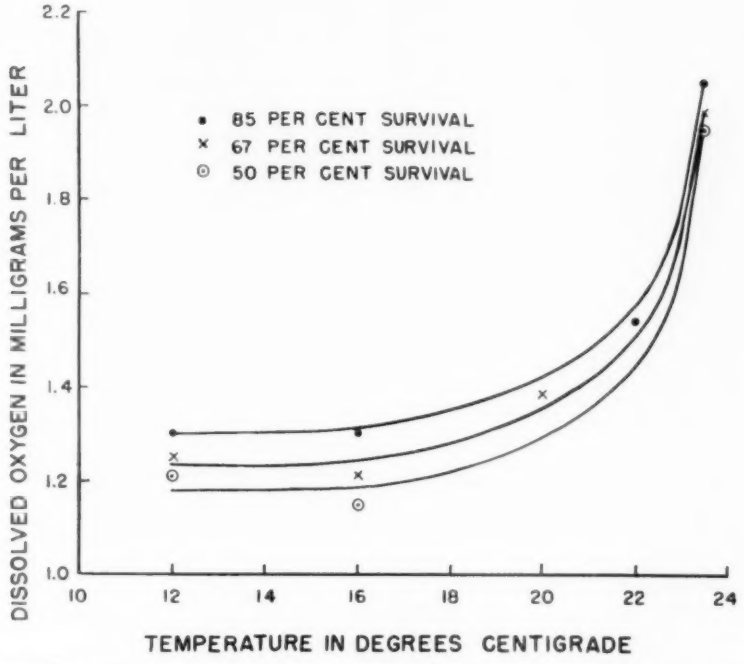

FIGURE 2.—Influence of dissolved oxygen and temperature on 24-hr survival of juvenile coho salmon in the fall season.

deviate from the stated average values by more than 0.5°C. The individual tests have been grouped and the recorded percentages of fish surviving at approximately the same mean dissolved oxygen concentrations and temperatures have been averaged for the sake of brevity and to facilitate the derivation of comparable indexes of tolerance, which are plotted in Figure 2.

Table 1 shows the mean percentages of test animals surviving after exposure to the experimental concentrations of dissolved oxygen for about one day only. Most of the tests were continued for longer periods, however, and it was noted that fish surviving at a given oxygen concentration for one day usually survived at that concentration for the longer exposure periods up to five days. Of the 35 tests recorded in Table 1 (including the second footnote), 15 continued for 5 days, 9 for 4 days, and 6 for 2 days. In 12 of the 30 tests which were continued for 2 days or longer, one or more of the 10 test animals died within the first day. The number of fish dying within one day in these 12 tests was 30 (25 per cent), and in none of them did the mortality during the first day exceed 50 per cent. Yet, only 1 additional death occurred in these same 12 tests and only 4 deaths occurred in all of the 30 extended tests after the first day. Had all the tests been continued for 2 days, and even for 4 or 5 days, it is apparent that the final results (survival percentages) would not have been markedly different from the 1-day test results reported in Table 1. Gradual acclimatization to reduced but not rapidly lethal oxygen concentrations, which has been demonstrated in ex-

periments with brook trout (5), evidently occurs also in coho salmon. In one experiment at 18°C, 9 juvenile coho salmon were held for 5 days at concentrations near 2 mg/l, and the oxygen concentration was then further reduced gradually. These fish died at concentrations (0.9 to 0.7 mg/l) averaging about 0.2 mg/l lower than the corresponding lethal concentrations (1.1 to 0.9 mg/l) for 10 unacclimatized fish. The latter fish had been held in well-aerated water before the oxygen content was gradually reduced within 8 to 10 hr to the rapidly lethal levels.

Development and Interpretation of Curves

Estimates of the dissolved oxygen concentrations that are lethal to 85, 67, and 50 per cent of the test animals at the different experimental temperatures, derived from the data presented in Table I, are plotted in Figure 2. Most of these values were obtained by graphical interpolation, after plotting the experimental data on probability paper, with mean survival percentages laid off on the probit scale and mean oxygen concentrations on an arithmetic scale. A straight line was drawn through two points representing in this graph oxygen concentrations lethal to some but not to all of the test animals at a given temperature. The points at which this line intersects the coordinate lines representing 85, 67, and 50 per cent survival then were located, and the corresponding oxygen concentrations were plotted against the temperature in Figure 2. The estimates for the test temperature of 23.5°C are based on the assumption that all fish which at this temperature could not tolerate for one day oxygen concentrations averaging 1.90 and 1.92 mg/l had died at these concentrations when the tests were prematurely discontinued after 16 hr. No serious error can result from this assumption, since the estimates would have been only slightly higher even had it been assumed that nearly all the fish (95 per cent) would have died within one full day at the test concentrations in question. In other tests the death of fish after more than 16 hr was relatively infrequent.

The available data did not make possible estimation by the interpolative method described above of dissolved oxygen concentrations tolerated by 85 and 50 per cent of the test animals at 20°C, and by 67 and 50 per cent of test animals at 22°C. Estimates of these concentrations can be derived, however, from Figure 2. The curves in Figure 2 were fitted for this purpose by inspection to the plotted points to obtain the best possible fit while maintaining a logical or congruous relation among the three curves. These curves do not necessarily represent accurately the true relation between temperature and the dissolved oxygen requirements of fully acclimatized juvenile coho salmon of uniform age and history. Nevertheless, it seems safe to conclude that the minimum oxygen concentrations tolerated by the fish for one day, after gradual reduction, are little different at varying temperatures between 12 and 20°C, but rise markedly at temperatures approaching the upper limit of thermal tolerance of young coho salmon, which has been reported to be near 25°C (11).

1953 Summer Tests

The results of experiments performed during the summer of 1953 were somewhat erratic. During this period heavy mortality occurred frequently among controls held in well-oxygenated water. In experiments in which controls survived, coho salmon tested in July at temperatures of 17.5 to 18°C proved nearly as resistant to low oxygen concentrations as those tested in November at temperatures near 16°C (Table I). However, at 20°C the fish proved somewhat more susceptible in early July than in the fall, requiring

apparently at least 0.1 or 0.2 mg/l more oxygen for survival; and at 22°C fish tested in August appeared to be far more sensitive than those tested in October. Most of the fish tested in August at 22°C succumbed within a day at oxygen concentrations between 2.0 and 2.2 mg/l, though not at higher concentrations. The significance of the latter observations is not entirely clear.

Food Consumption and Growth

The results of an experiment wherein three groups of recently captured yearling coho salmon were held for 30 days in winter at a uniform temperature near 18°C and at dissolved oxygen concentrations averaging 2.0 mg/l, 2.9 mg/l, and 9.0 mg/l (controls) are presented in Table II. A group of 10 fish, which had been weighed at the beginning of the test, was held in each of three 12-gal bottles in which the different oxygen concentrations were maintained. The water in the bottles was replaced at the rate of 500 ml/min. Each group of fish was offered 100 pieces of liver, averaging 0.05 g in weight, every other day, in the manner already described. The numbers of pieces of liver taken by the fish within each of four successive depth intervals into which each bottle was divided, as well as the total food consumption, were noted and recorded from the 14th to the 28th day of the experiment (last 8 feedings) only. The percentages of offered food particles consumed during this period by the different groups of fish are shown in Table II. With the exception of one fish which died on the 30th day of the test in the bottle with dissolved oxygen averaging 2.0 mg/l, all of the experimental fish lived for the duration of the 30-day test. The total weight of the fish in each bottle, including the weight of the single dead fish, was determined at the conclusion of the test. Table II shows the change in weight of each group of fish in the course of the entire test.

It will be noted that the fish held at oxygen concentrations averaging 2.0 mg/l consumed only a small fraction of the food offered, and they lost weight during the experiment. They seemed to be consuming somewhat more food during the first few days of the test, when no determinations and records of food consumption were made, but their appetite was soon markedly affected. The fish held at oxygen concentrations averaging 2.9 mg/l consumed nearly all of the food offered and gained weight, as did the control fish held in water with dissolved oxygen content near the saturation value. However, the weight gain of the fish at the reduced oxygen concentration was somewhat less than that of the controls. Unfortunately, their total initial weight was considerably greater than that of the controls, so that the results obtained with these two groups of fish are not entirely comparable. Had the control fish been larger, they perhaps

TABLE II.—Effects of Low Oxygen Concentrations on the Food Consumption and Growth of Yearling Coho Salmon Held for 30 Days at 18°C in Winter (Jan.–Feb. 1954)

Dissolved Oxygen (mg/l)		Number of Fish	Fish Surviving (per cent)	Food Taken* (per cent)	Total Weight of Fish (g)		Change in Weight of Fish	
Mean	Range				Initial	Final	Grams	Per Cent
2.0	1.8–2.4	10	90	21	55.9	52.2†	− 3.7	− 6.7
2.9	2.4–3.2	10	100	97	56.3	72.1	+15.8	+28.1
9.0	8.8–9.2	10	100	97	46.0	65.3	+19.3	+42.0

* Food taken from the 14th to the 28th day of the experiment (at the last 8 feedings) only.
† Includes the weight of the single dead fish, which died on the 30th day of this test.

would have gained less weight than they did, while consuming nearly all the available food, and the weight gain expressed as a percentage of the initial weight almost certainly would have been less than the reported gain.

The control fish took the proffered food more promptly than did those held at low oxygen concentrations. When the pertinent observations were made, the controls consumed, on the average, 87 per cent of the food particles before these had descended 5 in. below the water surface, and 94 per cent before the particles had fallen 10 in. The corresponding percentages for fish held at 2.9 mg/l average dissolved oxygen were 76 and 89 per cent. Almost all of the food particles consumed by both of these groups of fish were taken before they had fallen 15 in., whereas nearly one-fourth of the small amount of food eaten by the fish exposed to 2.0 mg/l DO was taken at greater depths, less than half (9 per cent of all the food offered) having been consumed before the food had fallen 5 in. from the surface. The total depth of the water in each test vessel was about 20 in., the neck of the bottle having been emptied before feeding commenced.

Summary of Additional Data

The results of the preliminary experiments just presented, obtained with yearling coho salmon in winter, may be somewhat misleading. They may create the erroneous impression that dissolved oxygen concentrations even as low as 3 mg/l can have little if any adverse influence on the survival, food consumption, and growth of juvenile coho salmon in general. In order to ensure against such misinterpretation of the data, pertinent additional data now available are briefly summarized here. These results of numerous experiments performed during the years 1955 and 1956, as well as the methods employed, have been fully reported by Herrmann (12).

With certain exceptions to be noted, the experiments were performed in the summer and fall, at a constant temperature of 20°C, with coho salmon in their first year of life. Ten fish of uniform size were used in each test at a given oxygen concentration. The fish were fed live marine amphipods (beach fleas) twice daily, in quantity always exceeding the amount consumed, and the excess was not immediately removed. It is believed, therefore, that neither the amount of food consumed by the fish nor their growth was limited by food availability in these experiments. Each group of test fish was weighed at the beginning and at the end of an experiment. The food supplied to each group and the uneaten excess removed were weighed daily. The duration of an experiment was about three to four weeks. Of 80 controls held at oxygen concentrations near the air-saturation value, only one fish died.

The survival of fish held at oxygen concentrations below 4 mg/l proved highly variable. In three tests at concentrations averaging 2.1 to 2.3 mg/l performed in 1956, mortality within 20 to 28 days ranged from 100 per cent (in May) to 0 per cent (in late November and early December, at 18°C). The fish lost weight in every case.

At oxygen concentrations averaging 2.7 to 3.3 mg/l, all fish died within two weeks in three tests performed in late July and August of 1955, and in a fourth test only 30 per cent remained alive after 19 days, when the test was discontinued. In each of these tests, the fish lost much weight (up to 32 per cent), while controls grew rapidly. Yet, in a test begun on October 15, 1956, the fish not only lived for 21 days at an oxygen concentration averaging 3.1 mg/l, but also showed a 48 per cent gain in weight. Controls at this time showed a weight gain of 103 per cent.

In May 1956, 18 of 20 salmon in their first year of life lived for 21 days

at oxygen concentrations averaging 3.1 mg/l and showed a weight gain of 13.4 per cent, while 19 of 20 controls lived and showed a weight gain of 100 per cent. At the same time, all of 10 yearling fish succumbed at the same mean oxygen concentration, as well as at a concentration of 2.4 mg/l. There were no yearling controls. It is possible that the susceptibility of yearling fish to low oxygen concentrations increases about the time of their seaward migration.

With very few exceptions (3 fish only), the juvenile coho salmon lived for the duration of the experiments (21 to 27 days) at oxygen concentrations averaging about 4, 5, 6, and 8 mg/l, in five tests at each concentration, performed in 1955 (July 21 to September 22) and 1956 (July 29 to November 4), each group of fish gaining weight. The mean weight gains of surviving fish at these four oxygen concentrations in the five experiments were found to be 56, 68, 88, and 92 per cent, respectively. The amounts of food consumed per gram of initial weight of the fish averaged 3.15, 3.44, 4.10, and 4.27 g, respectively. Increases in weight of the fish per gram of food consumed averaged 0.168, 0.188, 0.216, and 0.220 g, respectively.

Thus, under the conditions of these experiments, the rate of growth, the food consumption, and the efficiency of conversion of food to body weight generally decreased materially when the oxygen concentration was reduced to values below 6 mg/l, and they seem to have been somewhat depressed even at this concentration. They varied widely in different tests at the same oxygen concentration (especially at a concentration below 6 mg/l), but were always less for fish held at oxygen concentrations near 4 mg/l than for controls held at the same time at concentrations near 8 mg/l.

The fish proved more susceptible to the adverse effects of reduced oxygen concentration in experiments performed in 1955 than in experiments performed in 1956 at the same time of year. In both years these effects on juvenile coho salmon in their first year of life were most pronounced in the early tests, and became less marked later in the year, as the fish grew older.

Sulfite Waste Liquor Tests

Results of some comparative tests of the resistance of juvenile coho salmon to reduced oxygen concentrations in the presence and in the absence of calcium-base, sulfite-process pulp-mill waste liquor, performed with Marys River water in the fall of 1954, are presented in Table III. The concentration of sulfite waste liquor, which was added to the water after reducing its oxygen content to the desired level, was in every instance 1,200 mg/l liquor of 10-per cent solids content. Twelve-gallon test vessels were used, and the water was renewed at the rate of 550 ml/min. The dissolved oxygen content of the nitrogen-treated water (without waste liquor) flowing to each experimental vessel was determined repeatedly, as was also that of the effluent from each vessel receiving no waste liquor. The oxygen content of the effluents from bottles receiving the diluted sulfite waste liquor could not be reliably determined by chemical test, because of chemical interference by liquor constituents. However, it can be assumed that the decrease of the oxygen content of the water during passage through the test vessels was not usually greater when the water contained no waste liquor than when the liquor was present. Presumably, if there was any consistent difference, the greater reduction occurred when the water contained waste liquor, because of the oxygen demand (immediate and biochemical) of the liquor.

The data in Table III show, therefore, that the addition of 1,200 mg of sulfite waste liquor (with 10-per cent solids content) per liter of river water

TABLE III.—Survival of Juvenile Coho Salmon at Low Dissolved Oxygen Concentrations in the Presence and Absence of Sulfite Waste Liquor (1,200 mg/l Liquor of 10-Per Cent Solids Content)

Dates (1954)	Mean Temperature (°C)	Sulfite Waste Liquor	Dissolved Oxygen Concentrations (mg/l)				Percentage of 10 Test Animals Surviving*	
			Influent		Effluent			
			Mean	Range	Mean	Range	1 Day	2 Days
10/22–24	16	Absent	1.70	1.5–2.0	1.53	1.3–2.0	90	90
10/22–24	16	Present	1.82	1.5–2.0	—	—	90	80
11/12–14	18	Absent	1.67	1.6–1.8	1.41	1.3–1.6	80	50
11/12–14	18	Present	1.72	1.6–1.8	—	—	90	30
11/19–20	18	Absent	1.64	1.6–1.8	1.53	1.5–1.6	30	—
11/19–20	18	Present	1.72	1.7–1.8	—	—	50	—
12/19–21	16	Absent	1.76	1.5–2.1	1.62	1.4–1.9	50	40
12/19–21	16	Present	1.73	1.2–1.9	—	—	50	50
12/22–24	16	Absent	1.78	1.5–2.0	1.65	1.5–1.8	40	40
12/22–24	16	Present	1.74	1.5–2.0	—	—	60	40
Mean†	—	—	1.71	—	1.55	—	58	55
Mean‡	—	—	1.75	—	—	—	68	50

* In each of two control tests with well aerated water, with and without sulfite waste liquor, performed concurrently with every experiment reported, all of 10 fish survived.

† For tests excluding sulfite waste liquor.

‡ For tests including sulfite waste liquor.

did not materially increase the dissolved oxygen requirements of the fish. The mean oxygen content of the influent water for all of the five reported tests of partially deoxygenated water without sulfite waste liquor and the corresponding value for the five comparable tests of water with waste liquor added are nearly equal (1.71 and 1.75 mg/l, respectively). The mean percentages of test animals surviving for one or two days in the water without waste liquor and in the water with waste liquor also are not markedly different. Any considerable increase of the dissolved oxygen requirements of salmon exposed to diluted sulfite waste liquor should have resulted in

TABLE IV.—Survival of Sculpins, *Cottus perplexus*, Exposed to Various Concentrations of Dissolved Oxygen at Temperatures of 18 to 19°C, During Late Summer (Aug. 12–Sept. 11, 1954)

Dissolved Oxygen (mg/l)		No. of Tests	No. of Fish	Percentage of Fish Surviving				
Mean	Range			1 Day	2 Days	3 Days	4 Days	5 Days
1.18*	1.1 –1.25	3	30	0	0	0	0	0
1.27	1.2 –1.35	1	10	40	10	0	0	0
1.38	1.25–1.5	1	10	90	40	20	20	20
1.49	1.4 –1.6	1	10	100	90	80	60	60
1.64	1.55–1.7	1	10	100	100	100	100	100
2.31	1.7 –2.4	1	10	100	100	100	100	100
3.05	3.0 –3.25	1	10	100	100	100	100	100
Controls	—	5	50	100	100	100	100	100

* Mean of three test means.

markedly lower mean percentages of survival of these fish.

Tests with Sculpin

Table IV shows the results of a series of tests of the resistance of the sculpin *Cottus perplexus* to low oxygen concentrations at temperatures of 18 to 19°C, performed at the Yaquina Bay laboratory in the summer of 1954. Twelve-gallon test vessels were used, and the water in them was renewed at the rate of about 400 ml/min. The duration of each test was 5 days, and the numbers of fish surviving were recorded at daily intervals. It is apparent that the dissolved oxygen requirements of the sculpins at the stated temperatures are not very different from those of juvenile coho salmon at the same temperatures. It is noteworthy, however, that a large majority of the sculpins which succumbed at lethal or critical oxygen concentrations above 1.2 mg/l died only after exposure for more than one day to these low dissolved oxygen levels, and that several deaths occurred after more than 2 days. The oxygen concentrations tolerated for one day by only 50, 67, and 85 per cent of the test animals, estimated by interpolation in the same manner as were the corresponding values for coho salmon plotted in Figure 2, were found to be about 1.29, 1.32, and 1.36 mg/l, respectively. The median tolerance limit for an exposure period of 4 days has been estimated to be about 1.46 mg/l; and the corresponding 5-day value appears to be the same.

Discussion

Temperature Effects

The data of Burdick *et al.* (1) show that for trout of three species (brook, rainbow, and brown) the mean "lethal oxygen concentrations" (i.e., actually concentrations at which the fish turned over when confined in sealed vessels) increased by at least 40 per cent, and in some cases by more than 50 per cent, when the experimental temperature was increased from 12 to 20°C. The highest temperatures at which the experiments with trout were performed by these investigators were 20 to 22°C. They stated that "In all species studied, within the temperature ranges covered, the mean lethal oxygen concentrations plotted on the logarithmic scale against the temperatures on the arithmetic scale appear to form a straight line on semi-logarithmic graph paper." Graham's data (4) suggest a similar relationship in brook trout over a wide range of temperatures (3.5 to 23°C), but her estimates of lethal oxygen levels for trout placed in continually renewed (running) water, partially deoxygenated by means of nitrogen, were based on experiments with very few fish. A corresponding relationship between temperature and the minimum oxygen concentrations tolerated for one day by juvenile coho salmon is not suggested by the data reported here.

The curves plotted in Figure 2 suggest that critical oxygen concentrations for the salmon may increase by only about 10 per cent with a rise of temperature from 12 to 20°C, and may be almost independent of temperature when the temperatures are below 16°C, but there is a marked increase at much higher temperatures, particularly temperatures above 22°C. These curves are not deemed entirely reliable, for the tests at different temperatures were not performed simultaneously, and the fish probably were not yet completely adjusted to some of the test temperatures.

The influence of thermal acclimatization on the respiratory metabolism of fishes and their resistance to lack of oxygen has been long established (13) (14). Recent exposure of the salmon tested at 16°C to a somewhat higher temperature (20°C), and of those tested at 12°C to a somewhat lower temperature, could have resulted in their failure to exhibit a difference of

resistance which they might have shown after complete acclimatization to the test temperatures and consequent stabilization of metabolic rates. Nevertheless, there can be little doubt that the influence of temperature on the minimum oxygen levels tolerated by juvenile coho salmon under the experimental conditions described is very different from its influence on the tolerance limits of trout as determined by Burdick *et al.* under their somewhat different experimental conditions. It is not clear to what extent this disparity is ascribable to differences between the species, and how much of it may be attributable to differences of experimental conditions or methods of tolerance evaluation.

Downing and Merkens (6) have reported that the resistance of rainbow trout to reduced oxygen levels, to which the fish were suddenly exposed in running water which had been treated with nitrogen, decreased markedly with rise of temperature from 10.6 to 16.4°C, but not with a further rise of temperature from 16.4 to 19.9°C. Other species of fish tested by these authors did not yield corresponding results. Mirror carp seemed to require more oxygen than the rainbow trout for survival for a period as long as one week at the temperature of 19.9°C, but at the lower test temperatures they proved much more resistant to low oxygen levels than the trout. Even at 19.9°C they withstood for short periods (less than 2 days) levels much lower than those tolerated by the trout. Lozinov (15), in reviewing several other investigations with various fishes, has noted that the data reported in the literature appear to be somewhat contradictory or variable. He remarked that in some instances a marked increase of the threshold concentration of dissolved oxygen with increasing temperature has been reported, whereas in other instances there was almost no change, or else pronounced increases occurred only at temperatures near the upper limits of thermal tolerance (i.e., as reported here for coho salmon).

Variability of Tolerance

With regard to the critical levels of dissolved oxygen at low temperatures, there is good agreement between the experimental results reported here and the comparable published data of other investigators who have tested the resistance of coho salmon fingerlings to oxygen deficiency in flowing water at temperatures of 10.9 to 12.7°C (2) (3). The published data on the resistance of other salmonid species are variable and are not often closely comparable with the data presented here, because of differences of experimental conditions and methods. Some of the data based on flowing-water tests of comparatively long duration such as those reported here (2) (4) (5) (6) suggest that young brook trout (*Salvelinus fontinalis*) and rainbow or steelhead trout (*Salmo gairdneri*) may be somewhat more sensitive than the juvenile coho salmon. Even results of some tests of relatively brief duration, such as those of Burdick *et al.* (1), indicate that dissolved oxygen concentrations above 2.0 mg/l can be rapidly disabling to brook trout and brown trout (*Salmo trutta*) at moderately high temperatures below 20°C. The relatively high resistance shown by the coho salmon at these temperatures in experiments reported here may be ascribable partly to more favorable experimental conditions (e.g., the spacious test vessels, the gradual reduction of dissolved oxygen only after the fish have been held in the vessels at high oxygen concentrations for one day, etc.).

The average resistances of the juvenile coho salmon to low oxygen concentrations did not prove uniform even in similar experiments at like temperatures. Fish from Beaver Creek, tested in 1953 in spring water at the Yaquina Bay laboratory, appeared to be more resistant in the fall than in summer at relatively high temperatures only. At

somewhat lower test temperatures (16 to 18°C), they proved consistently more resistant than were the Yaquina River fish tested at the same temperatures at Corvallis in the fall of 1954, using Marys River water. As Table III shows, only 58 per cent of the latter fish survived for one day in the test vessel receiving no sulfite waste liquor and with dissolved oxygen in the effluent water averaging about 1.55 mg/l. On the other hand, oxygen concentrations averaging about 1.3 mg/l were tolerated by more than 80 per cent of the Beaver Creek fish tested at the Yaquina Bay laboratory in November and July of 1953 at corresponding temperatures (about 16 to 18°C). At 20°C the susceptibility of the latter fish to oxygen deficiency in the same laboratory in July 1953 approached that of the Yaquina River fish tested at Corvallis in the fall of 1954 at temperatures of 16 to 18°C. However, other results (16) have shown mean oxygen concentrations greater than 1.8 mg/l to have been necessary in July 1955 for survival of more than 50 per cent of juvenile coho salmon from the Yaquina River drainage basin for one day in filtered Marys River water at temperatures near 20°C. It must be concluded that the resistance of juvenile coho salmon to oxygen deficiency varies considerably not only with temperature, but probably also with the season or with the age of the fish, and with other factors or variables such as the source, history, and condition of the animals and perhaps the quality of the water.

Sulfite Waste Liquor

The observation that the addition of 1,200 mg of sulfite waste liquor (or about 120 mg of sulfite waste liquor solids) per liter of Marys River water did not cause any material increase of the dissolved oxygen requirements of coho salmon indicates that these requirements are not necessarily affected markedly by such impurities in the water. It is not regarded as conclusive evidence, however, that sulfite waste liquor in the tested concentration cannot have an effect on the oxygen requirements of salmonid fishes, since wastes from different pulp mills vary considerably in their composition. Townsend and Earnest (3) reported a demonstrable but variable effect. Townsend and Cheyne (17) suggested that the variability of the results may have been due to variations of the pH of waste samples and dilutions, these authors having observed increased susceptibility of coho salmon to low oxygen concentrations in water with reduced pH. The influence of pH and of free carbon dioxide concentration on the dissolved oxygen requirements of juvenile coho salmon has been further investigated (16). The results of these studies are to be reported in a future publication.

Non-Lethal Effects of Low DO

While the yearling coho salmon in winter lived for 30 days at oxygen concentrations averaging 2.0 mg/l and temperatures near 18°C, their sluggish behavior, reduced appetite, and consequent loss of weight clearly showed the oxygen concentrations to be inadequate when they persist for long periods. Dissolved oxygen concentrations averaging 2.9 mg/l have not been shown to be markedly detrimental to the yearling coho salmon by the results of the experiments reported (at 18°C). The fish held under these conditions did not grow as much as the controls held in well-oxygenated water, but it has been noted already that the difference could have been due, at least partly, to the smaller initial size of the controls, which presumably required less food for maintenance. The quantities of food consumed by these two groups of fish apparently were equal. It is noteworthy, however, that, had more food been available, both groups probably

would have consumed more, inasmuch as feeding was infrequent and on many occasions all of the food was consumed. Repeated additional experiments, wherein juvenile coho salmon held at 20°C and at varying oxygen concentrations were frequently offered all the live food (amphipods) they would consume, have yielded more instructive results. They showed that, in the presence of an abundance of food, considerable depression of food consumption and growth of juvenile coho salmon can occur at reduced oxygen concentrations well above 3 mg/l, and that concentrations near 3 mg/l sometimes can be fatal after moderately prolonged exposure. The fish in these tests may have consumed more food than they would have consumed under similar water quality conditions in their natural habitat, and the test temperature was rather high. Still, oxygen concentrations near 3 mg/l obviously cannot be said generally to be sufficient for the requirements of feeding juvenile coho salmon in their natural environment.

Requirements of Sculpin

Although the bottom-living sculpin, *Cottus perplexus*, is believed to be less active than the salmon, its dissolved oxygen concentration requirements in standing water do not appear to be very different from the requirements of juvenile coho salmon. The sculpin normally inhabits cool and well-oxygenated waters, along with trout and salmon. It is interesting to note that some warm water fish species, such as the smallmouth bass, which are normally more active than the sculpin even in moderately cool water, apparently have minimum dissolved oxygen requirements substantially less than the requirements of the salmonids (1). The observation that the sculpins, unlike the salmon, often died within two to four days at critical oxygen concentrations which were tolerated for one day suggests that their capacity for acclimatization may be less than that of the salmon, perhaps because there can be little compensatory depression of their activity under the adverse conditions.

Summary

The dissolved oxygen requirements of some cold-water fishes, under conditions necessitating no vigorous activity on the part of the test animals, have been investigated by holding the fish in flowing (continually renewed) water with dissolved oxygen content gradually reduced to constant levels by means of nitrogen.

In a series of experiments performed in the fall, minimum oxygen concentrations tolerated for one day by juvenile coho salmon were found to change little with changes of temperature between 12 and 20°C, but increased markedly at temperatures approaching the upper limit of thermal tolerance of the fish.

At constant temperatures of 20°C and less, in summer and fall, fasting juvenile coho salmon tolerated for one day oxygen concentrations well below 2 mg/l, but not as low as 1 mg/l. The one-day tolerance limits evidently are not much different from corresponding limits of tolerance for longer exposure periods up to five days, most of the observed mortality at critical oxygen concentrations having occurred in the longer tests during the first day of exposure.

Most yearling coho salmon tested in winter lived for 30 days at temperatures near 18°C and oxygen concentrations averaging 2.0 mg/l, but they were sluggish, consumed little of the food offered, and lost weight during the test. At oxygen concentrations averaging 2.9 mg/l the fish fed well and gained weight, but probably were somewhat affected. Briefly summarized additional experimental results show higher concentrations to be decidedly detrimental to juvenile coho salmon

under certain conditions in other seasons.

The presence of 1,200 mg of a sulfite-process pulp-mill waste liquor (with 10-per cent solids content) per liter of water had no demonstrable effect on the minimum dissolved oxygen requirements of juvenile coho salmon.

The resistance of the sculpin *Cottus perplexus* to reduced oxygen concentrations at temperatures of 18 to 19°C did not differ markedly from that of the juvenile coho salmon, but sculpins which survived at critical dissolved oxygen levels for one day often succumbed at these levels within three or four days.

Acknowledgments

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EXECUTIVE RESERVISTS MEET

Water and Sewerage Industry and Utilities Division, National Defense Executive Reservists, Washington Meeting, May 12–13, 1959. Front row, l. to r.: H. W. Hitzrot, Dorr-Oliver, Inc.; D. L. Muss, Consulting Engineer, North Bergen, N. J.; R. Lancaster, Water Superintendent, Kearney, Nebr.; G. P. Gabosch, M & H Valve & Fittings Co.; W. L. Picton, Director, Water and Sewerage Division, BDSA; R. Hebert, Filtration Equipment Corp.; L. L. Smith, Smith-Blair Co.; A. B. Kaltenbach, Dept. of Public Works, Baltimore County, Md.; J. C. Crenshaw, American Water Works Service Co., Islington, Mass.; C. W. Wilson, Superintendent of Water Works, Salt Lake City, Utah; H. S. Howe, Lock Joint Pipe Co. Back row, l. to r.: X. D. Murden, Superintendent of Water Works, Portsmouth, Va.; G. A. Shaffer, Water Works Commissioner, Detroit, Mich.; C. H. Bagwell, Manager, Water Works, Knoxville, Tenn.; W. M. Franklin, Superintendent of Water Works, Charlotte, N. C.; M. C. Hagar, Manager, Water Works, Sedalia, Mo.; O. E. Walker, Mueller, Ltd., Sarnia, Canada; L. Louis, Manager, Gary-Hobart Water Co., Gary, Ind.; H. B. McCoy, Administrator, BDSA; R. H. Ritter, Consulting Engineer, Baltimore, Md.; C. Oeschle, Assistant Secretary of Commerce for Domestic Affairs; H. A. White, Mueller Co.; C. F. Wertz, Director, Water and Sewers, Miami, Fla.; J. B. Cook, Hays Manufacturing Co.; W. R. Ladue, Superintendent of Water Works, Akron, Ohio.; H. F. Bower, James B. Clow & Sons, Inc., Chicago, Ill.; R. V. Ford, Ford Meter Box Co.; H. F. Seidel, Manager, Water and Sewers, Ames, Iowa.

THE OPERATOR'S CORNER

FIELD TRIP TO THE TREATMENT WORKS OF A NEW REFINERY

By John D. Frame

Cities Service Research and Development Company, New York, N. Y.

Editors Note:—The following article about the wastewater treatment works at Cities Service's new Trafalgar refinery in Bronte, Ont., is really four articles in one. If we seem to be a bit confusing we ask you first to examine this piece as if you were on a field trip; then examine it as an example of what really good, pertinent photographs can do for almost any paper; then appraise it as an illustration of how to tell a "public relations" story in pictures; and finally, analyze the massed public relations effect that stems from such items as the attractive appearance of the treatment building, the lure of the picture window in the laboratory, the sight appeal of the multicolored flowsheet mounted on the lobby wall, and last, but by no means least, the aquarium.

Full credit for the photographs used in this article goes to J. Alex Langley through the courtesy of the Cities Service Company.

On May 26, 1959, Cities Service Oil Company, Limited, officially opened its Trafalgar refinery in Bronte, Ontario. In doing so it also opened a new, modern, waste treatment plant. An aerial view of the 20,000-bbl/day refinery is seen in Figure 1. The treatment plant is in the foreground.

The Trafalgar plant is designed to treat a variety of wastes—everything, in fact, from the water used in the refining process, to tank drawoffs and sanitary wastes, as well as leakage from equipment, pump glands, and pipelines—in other words, all the wastewater produced in a large, modern refinery. Following treatment, the water is discharged to Lake Ontario.

In treating the refinery wastes many benefits, both direct and indirect, are derived. For example, several thousand barrels of "lost" oil are recovered every month. Even more important, the treatment works is securing the goodwill of the townspeople, farmers, and sportsmen. One of the ways good relations are fostered is by encouraging visitors to inspect the treatment facilities. Normally, tours begin and end at the treatment building and aquarium shown in Figure 2. A group beginning a tour is pictured in Figure 3. In the background of this photograph is a wall-mounted, completely electrified, colored flowsheet of the treatment process which is reproduced in Figure 4.

Treatment Units

In refinery wastes there are two substances that cause more trouble than

FIGURE 1.—Aerial view of the Trafalgar refinery. The treatment plant is in the foreground. Visible in the left center are the treatment building and aquarium; in the right center are the separator tanks; in the right foreground are two equalization basins; in the left foreground are three holding basins.

all the other wastes combined—phenols and waste oil. Both are pollutants. Phenol compounds make water smell and taste like carbolic acid; and oil, of course, is unsightly as well as a taste producer. Phenols are, moreover, very difficult to remove from water.

Strictly speaking, there are two kinds of wastewater in the Trafalgar refinery: storm water runoff and process wastes. Storm water runoff from noncontaminated areas drains through an independent system. All other wastes require complete treatment.

Oil Separator

The waste flow averages 300 gpm, although it may vary considerably from one moment to the next. After the actual flow is measured by a Parshall flume, it goes to the oil separator (Figure 5). Here the wastewater is allowed to stand long enough so that runaway oil can float to the top and heavy material settle to the bottom. Mechanical rakes then skim the oil off the top and collect the sludge deposited on the bottom. The recovered oil is sent back to the refinery for processing and the sludge is pumped to a thickener.

The water in the separator basin, now rid of sludge and free of oil, still contains dissolved chemicals and finely dispersed waste along with oil that is emulsified or bound to minute particles of solid matter. These remaining pollutants are removed in other treatment units.

Equalization Basin

From the oil separator, the effluent is sent to an equalization basin—a rec-

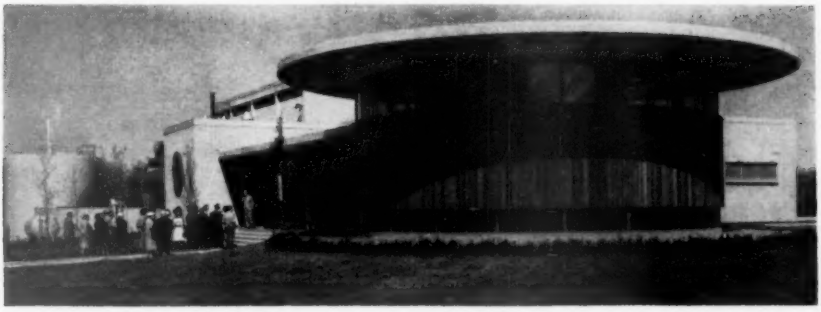

FIGURE 2.—Plant visitors gather at treatment building lobby and aquarium for briefing before tour begins.

FIGURE 3.—The operations on the other side of the laboratory picture window hold the interest of plant visitors. Notice the wall-mounted flowsheet in the background.

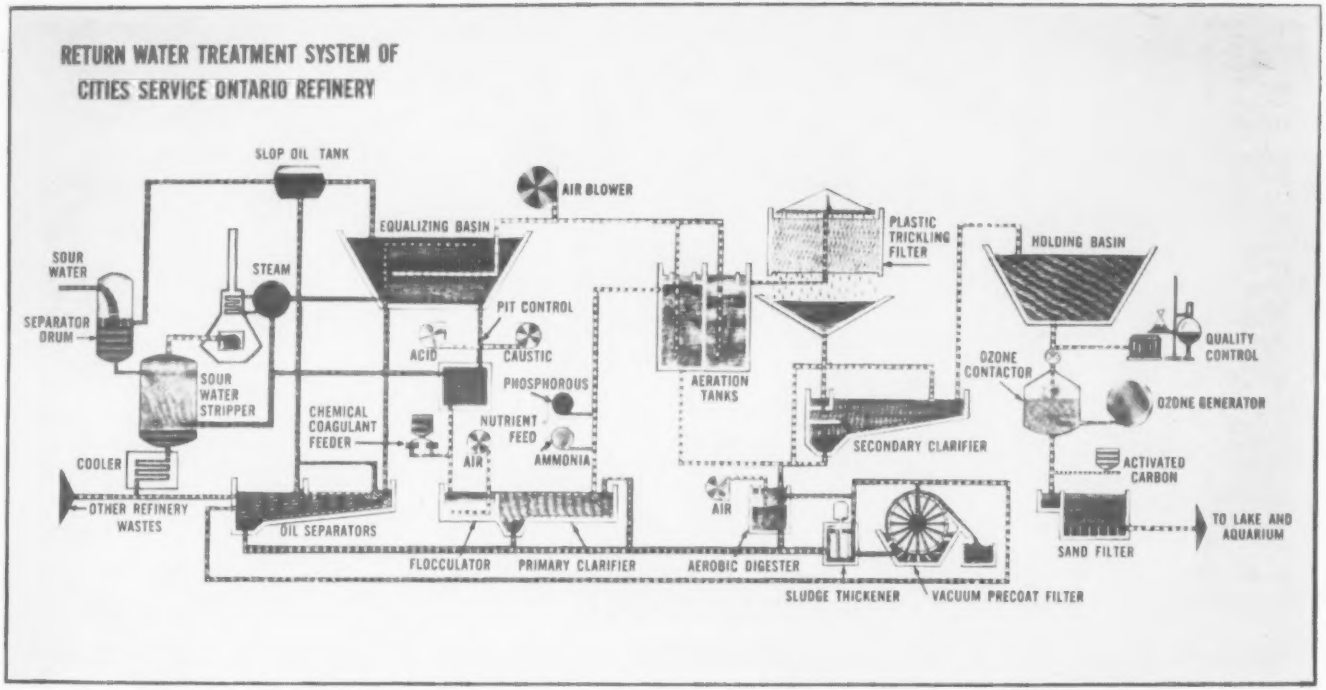

FIGURE 4.—Electrified flowsheet of waste treatment process at Cities Service's Trafalgar refinery, Bronte, Ont.

FIGURE 5.—Separator tanks. Moving rakes recover the floating, runaway oil and return it to the refinery.

tangular pit large enough to hold one day's flow of waste (Figure 6). The basin has several functions. In the first place, refinery wastes do not flow at a constant rate. The flow of sanitary waste, for example, is greatest when each labor shift goes off duty. Certain other wastes are added to the system only during breakdown or repair. Secondly, the chemical nature of refinery wastes will obviously vary considerably over any 24-hr period. Strong acids predominate at certain times, and powerful caustics during others. However, by running all the wastes into one large basin, these extreme variations can be leveled out. The acids and bases, for example, can undergo partial dilution and neutralization. Suspended solids can be uniformly dispersed throughout the basin. Finally, and equally important, the flow of wastewater into the treatment units can be maintained at a fairly constant rate. Thus, the wastewater entering the treatment plant will vary only slightly over a 24-hr period—and allow the operator sufficient time to make the necessary and minor adjustments.

Three sets of pipes enter the equalization basin: one carries steam; another carries air; and the third brings in the

FIGURE 6.—This equalization basin permits the operator to maintain a constant flow of wastewater to the treatment building. Visible here is the distribution pipe bringing in the effluent from the oil separators.

effluent from the separator tank. This third pipe is perforated (Figure 6) and centrally located so that it distributes the incoming waste down the full length of the basin. Air is bubbled in to aid oxidation and insure thorough mixing. Steam pipes prevent the effluent from freezing in the winter. Provision is made to skim off any free oil that may have escaped the separator tank, and there is a spare equalization basin in case the flow becomes too great for one basin to handle.

Flocculation-Clarification Tanks

From the equalization basins, the waste flows by gravity to a pump pit in the treatment building. By this time, the acid and caustic wastes probably will have neutralized each other. However, if the waste is still too caustic or acidic, it can be neutralized in the pump pit. Following this, the neutralized waste is pumped through a heat exchanger where its temperature is brought up to 95°F. A solution of ferrous sulfate (Figure 7) is then added

FIGURE 7.—Ferrous sulfate is added to the solution tanks from overhead storage. After mixing, the solution will be added to the heated wastewater to bring about removal of the finely dispersed material and emulsified oil.

and mixed with the waste in one of two rectangular flocculation-clarification basins. Each of these tanks is divided by a perforated wooden wall into two sections. In the first section, air is bubbled up through the water to insure thorough mixing of the waste and ferrous sulfate (Figure 8). At the same time, the newly formed floc and heavy particles are kept near the surface. The waste then passes through the perforated divider into the quiescent half of the tank (Figure 9). Here the heavy particles settle to the bottom where they are scraped to one end and collected in a hopper. All floating material is skimmed into an open pipe near the outlet end of the tank. The remaining wastewater passes beneath the skimming pipe, out into a channel, and thence to the primary aeration tanks—and the center of the treatment process.

Aeration Tanks

On arriving at the primary aeration tanks (not shown), the influent overflows from troughs running the full length of each tank. Near the bottom of the tank, on one side, are distribu-

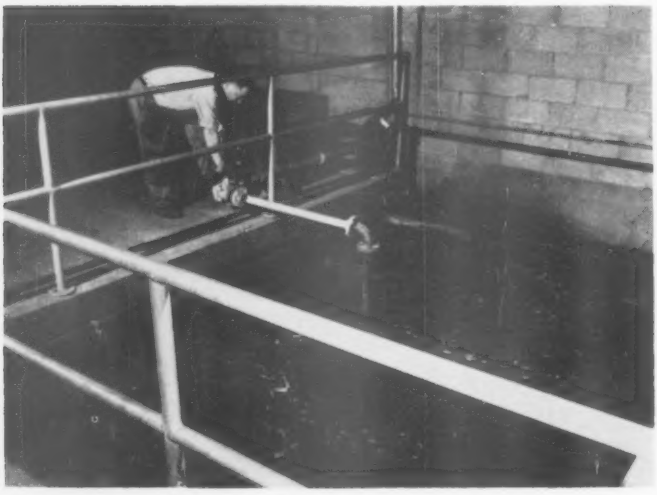

FIGURE 8.—Flocculation-clarification tank. Operator adjusts air bubbler to make certain the waste and ferrous sulfate solution are thoroughly mixed.

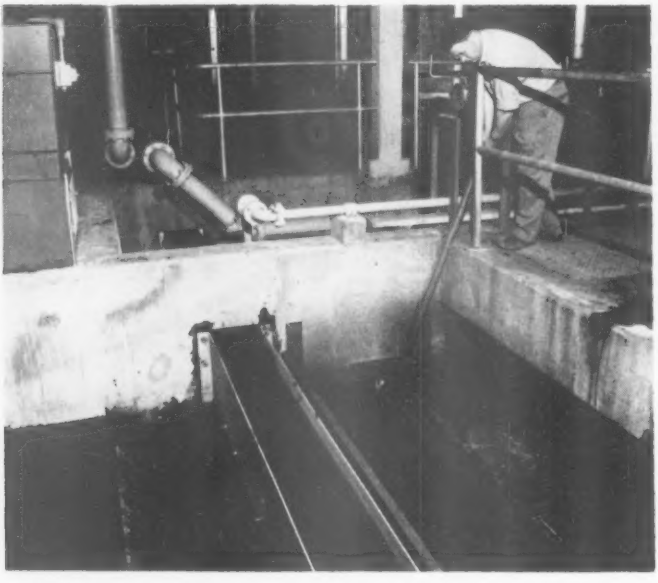

FIGURE 9.—Flocculation-clarification tank. Operator adjusts the skimming pipe to remove a mixture of floc and de-emulsified oil from the quiescent half of the tank. Mechanical scrapers remove sludge from the bottom. The clarified waste flows into the channel at far left.

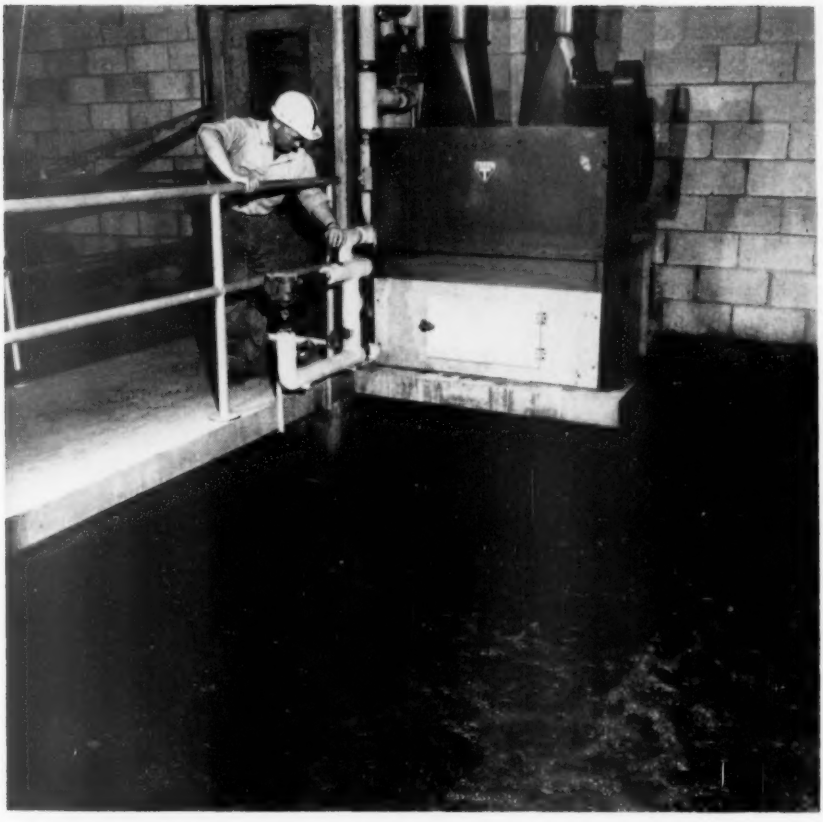

FIGURE 10.—Secondary aeration tank. Notice that the aeration tanks are in the treatment building.

tion pipes designed to release air in a manner which imparts a spiral motion to the wastewater. The incoming waste drops into this rolling mass and is quickly dispersed.

In the primary and secondary aeration tanks (Figure 10) biological oxidation takes place. Effective though bacterial oxidation is, however, the process still does not remove all the pollutants. A few of these compounds—particularly some of the phenolics—remain unchanged. Consequently, they must be removed by further processing.

Trickling Filters

From the secondary aeration tank, the waste is pumped to one of two deep trickling filters (Figures 11 and 12). At times of low flow, recirculation is practiced.

Secondary Clarifiers

The discharge from the trickling filters flows to the secondary clarifiers which are equipped with sludge collectors. Floating material is skimmed to a slotted pipe on the outlet side.

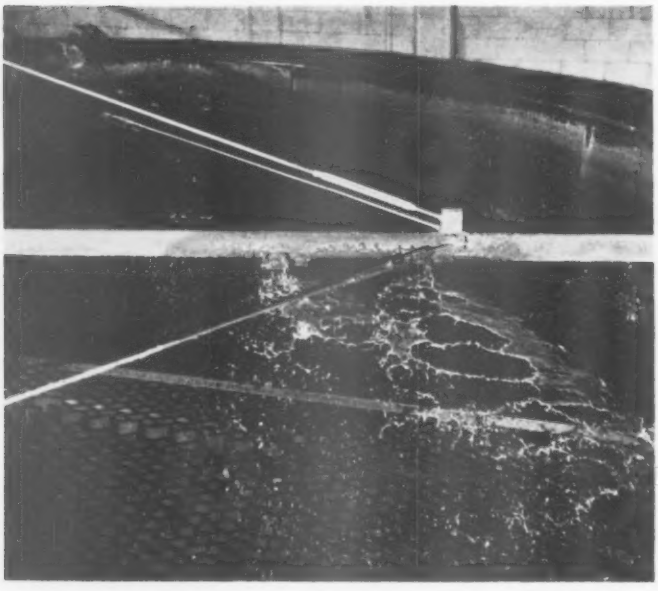

FIGURE 11.—Camera catches sheet of wastewaster being distributed over top of the trickling filter.

FIGURE 12.—Deep tanks at right of picture are the trickling filters.

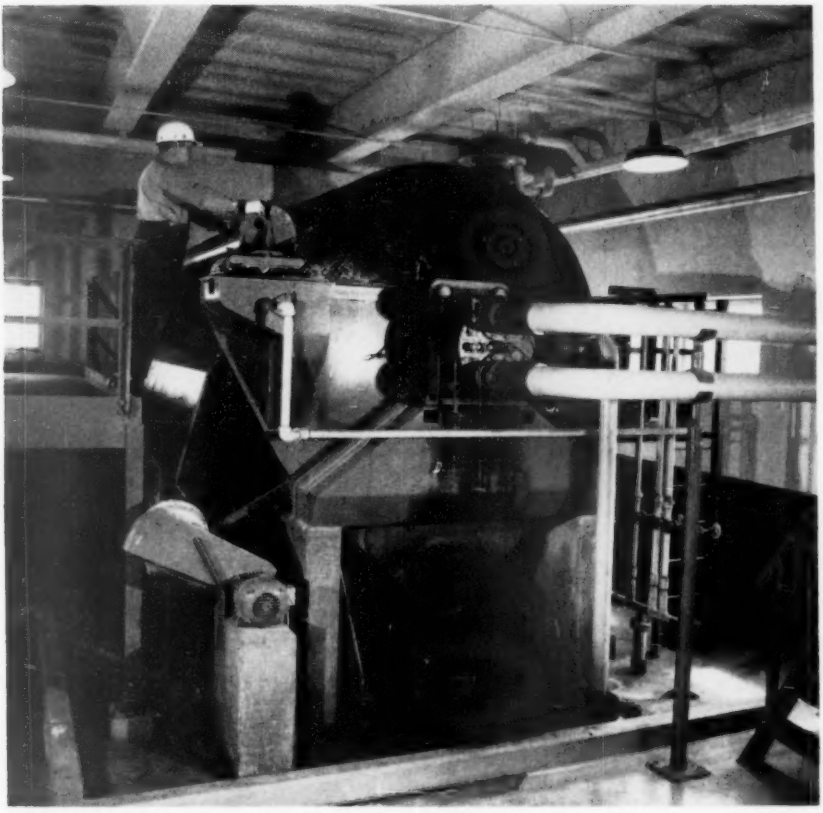

FIGURE 13.—Sludge is pumped from the thickener, partially dried on the vacuum filter, and hauled away.

The clear wastewater passes under this pipe, into a trough, and out to the holding basin located near the equalization basins.

Sludge Handling

Sludge from the oil separator and chemically precipitated sludge from the primary clarifier, as well as skimmings from the primary and secondary clarifiers, are pumped to the sludge thickener outside the building (not shown). The thickened sludge is then piped back to the building, partially dried on a vacuum filter (Figure 13), and hauled away by truck.

The bacterial sludge in the secondary clarifier passes, however, to the return sludge sump from where it is pumped to a concrete division chamber. From here one portion of the sludge is returned to the primary aeration tanks. The other portion of the sludge goes to the aerobic digesters. Here the bacteria are kept in constant motion, but they are deprived of chemical food. As a result, they devour each other, the debris settles to the bottom, and is conveyed to the sludge thickener outside the building. From there it goes to the vacuum filter for dewatering.

In addition to the carbon and hydrogen present in refinery wastes, the recirculating bacteria also require phosphorus and nitrogen. These elements, in the form of phosphoric acid and

FIGURE 14.—Holding basin contains treated water from which most of the original phenols and other chemicals have been removed.

anhydrous ammonia, are added to the influent of the primary aeration tanks.

Holding Basin

By the time the wastewater reaches the holding basin (Figure 14), most of the original phenols and other chemicals should be absent. Samples are taken to make sure that the water meets certain rigorous standards. If the analyses prove the treated waste to be unacceptable, it is run through the entire treatment plant again. The Trafalgar plant has, in fact, been designed to handle the usual daily flow of raw waste plus an equal quantity from the holding basins should such a procedure prove necessary.

Ozone Generator

Assuming that the water in the holding basin does meet the standards, it is pumped to a large stainless steel tank where it is mixed with ozone (Figure 15). This treatment is necessary because there still are, in spite of all earlier processing, small amounts of the undesirable phenolic compounds in the wastewater. It is possible, however, to oxidize most of the remaining phenolics by supplying oxygen in the form of ozone. The waste in the holding basin is discharged into the top of the ozone reaction tank and flows down through the vessel. Ozone is pumped to the base of the tank and

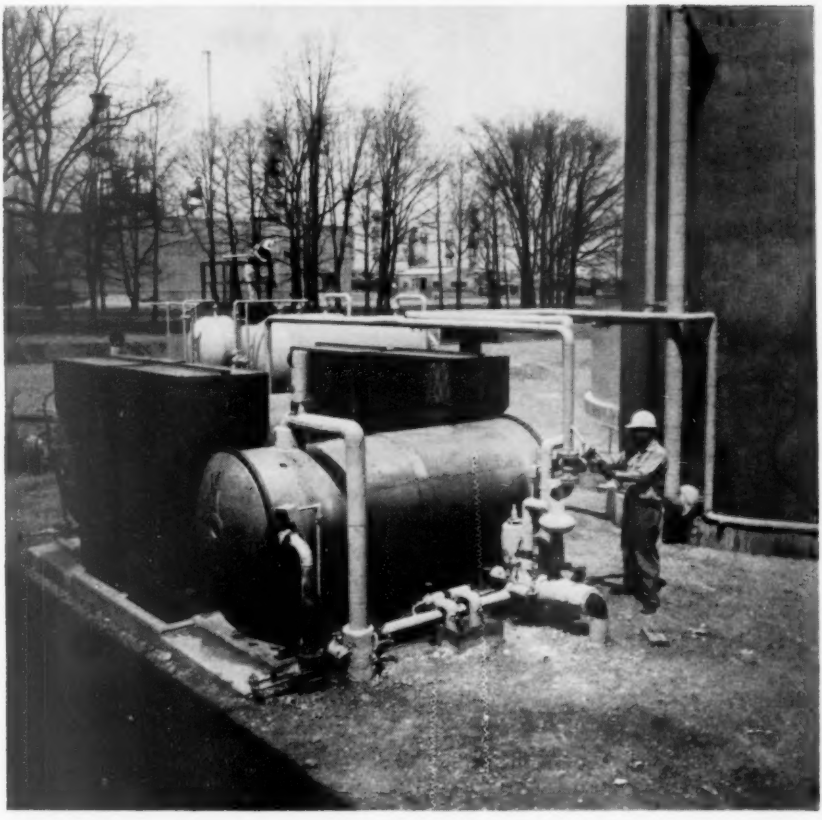

FIGURE 15.—Ozone is generated in this cylindrical drum and then mixed with the treated wastewater in the reaction tank at the right.

diffused into the liquid. The ozone is dispersed in fine bubbles so that the contact between gas and liquid will be at a maximum.

Ozone also serves a second purpose. At the same time it oxidizes the phenolic compounds it also disinfects the water. Normally, in most water disinfection procedures, chlorine is used. But in dealing with phenolic compounds, the use of chlorine could be detrimental, for chlorine and phenols usually combine to form compounds that taste far worse than the phenolic compounds themselves.

The effluent leaving the ozone reaction tank has the smell and taste of fresh spring water. Yet it still contains traces of phenolic compounds and a slight amount of turbidity.

To rid the water of these last pollutants, it is subjected to two simple and final treatments. In the first, activated carbon is added to adsorb the last of the phenolic material. Then the water is filtered through a rapid sand filter.

Since the carbon will be retained on the surface of the sand filter, it will eventually build up and hinder the flow of water. Periodically, then, the filter must be backwashed. The wash

FIGURE 16.—Plant visitors asking final questions at the end of their tour. In the background is the plant aquarium to which is fed treated refinery wastewater.

water is then piped back to the equalization basin for processing along with the raw refinery waste. The fine material and carbon removed from the filter bed will ultimately be removed by the ferrous sulfate treatment mentioned earlier.

With this final treatment, water is obtained that is clear and sparkling, free of odor and taste, rid of pathogenic organisms, and rich in dissolved oxygen. Following this final step, the water flows back to Lake Ontario, better in many respects than the raw waters from which it originally came.

Aquarium

As mentioned earlier, tours of the treatment plant usually end at the point of beginning—the treatment building and aquarium. In Figure 16 a group of visitors is shown at the completion of their tour. In the background is the plant aquarium. Here varieties of Lake Ontario fish swim unconcerned in completely treated refinery wastewater. This feature of the treatment works is one of the main centers of attraction (Figure 17) and heightens interest in the pollution control endeavors of the Company.

FIGURE 17.—Aquarium is the center of attraction for many visitors.

IRON AND PHOSPHATE CHANGES DURING SEWAGE TREATMENT

By T. Stones

Manager, Sewage Disposal Works, Salford, England

IRON

Fowler and Ardern (1) found that although iron was deposited during the passage of sewage through septic tanks there was a tendency for some which was originally present in suspension to pass into solution. They also found that part of the iron present in the tank effluent was in true solution and part in colloidal dispersion. In general, however, there seems to be only limited information available on the subject of iron removal during sewage treatment. In view of this the

TABLE I.—Effect of Sedimentation on the Iron Content of Sewage

Run No.	Iron Content (mg/l)	
	Tank Influent	Tank Effluent
1	4.00	3.10
2	5.95	3.40
3	4.75	3.10
4	6.25	3.15
5	4.60	3.30
6	4.75	3.00
7	3.90	2.60
8	5.75	3.00
9	5.95	3.10
10	4.85	2.95
11	4.80	2.35
12	3.30	2.45
13	5.60	2.80
14	5.95	2.95
15	5.15	3.10
Avg	5.04	2.96
Removal (%)	41	

removal of iron during sedimentation, chemical precipitation, biological filtration, and activated sludge treatment was studied.

Analytical Technique

The reagent used for the determination of iron was *o*-phenanthroline. A suitable volume of sample (100 or 250 ml) was digested with 5 ml of concentrated sulfuric acid until the organic matter was destroyed. The residue was then diluted with water and boiled for a few minutes to ensure complete solution of the iron. Otherwise decidedly low results were obtained. The solution was then cooled and made up to 250 ml in a graduated flask. An appropriate volume of solution (*e.g.*, 25 ml) was then taken, 1 ml of 10 per cent w/v hydroxylamine hydrochloride and 2 ml of 0.25 per cent w/v *o*-phenanthroline were added and the solution was rendered alkaline with dilute ammonia. After making to 50 ml the iron content of the resulting orange-pink solution was determined photo-electrically using blue-green light of 500 mμ wave length.

Sedimentation

The effect of sedimentation on the iron content of sewage was investigated by determining the amount of iron in the normal 24-hr composite samples of tank influent and tank effluent at the Salford sewage works where the sedimentation tanks have a nominal detention period of 12 hr. The results are given in Table I and show that sedimentation reduces the iron content of the sewage by about 40 per cent.

By determining the amount of iron present in the paper filtrates from composite samples of tank influent and tank effluent (Table II) it was found that the amount of soluble and colloidally dispersed iron increased by about 17.5 per cent during tank treatment thus confirming Fowler and Ardern's observations. As shown in Table III, however, there was a decrease of about 16 per cent in the amount of iron in the paper filtrate on

TABLE II.—Effect of Sedimentation of Sewage on the Iron Content of the Paper Filtrate

Run No.	Iron Content (mg/l)			
	Tank Influent		Tank Effluent	
	Total	Paper Filtrate	Total	Paper Filtrate
1	7.70	2.10	3.40	2.20
2	7.00	2.15	3.55	2.30
3	7.10	1.85	3.85	2.15
4	5.60	1.55	2.85	1.95
5	4.80	1.60	3.00	1.80
6	5.90	2.00	3.75	2.15
7	6.50	1.60	3.25	1.95
8	5.60	1.60	3.25	1.95
9	6.90	1.35	3.00	1.55
10	5.90	1.40	3.45	1.85
11	3.10	1.10	2.70	1.85
12	4.60	1.35	2.80	1.85
13	5.60	1.55	3.15	1.70
14	5.20	1.40	3.00	1.60
15	6.30	2.30	3.55	2.45
Avg	5.85	1.66	3.24	1.95

quiescent settlement of samples for 18 hr in the laboratory which suggests that the increase that occurs during tank treatment may arise from the decomposition of the sludge accumulated in the sedimentation tanks.

In order to ascertain if the biological activity which occurs during sedimentation had any effect on the deposition of iron, comparative experiments were made using sterilized and unsterilized samples. For each of these experiments the iron content of a sample of sewage was first determined. The sample was then divided into two 1-liter portions one of which was sterilized by the addition of a few drops of a saturated solution of mercuric chloride. The two portions were then allowed to settle for 18 hr when the supernatant liquors were siphoned off and their iron contents determined. From the results in Table IV it does not appear that the deposition of iron during sedimentation is affected to any appreciable extent by the biological activity which occurs.

TABLE III.—Effect of Laboratory Settling on the Iron Content of the Paper Filtrate

Run No.	Iron Content (mg/l)			
	Unsettled Sewage		Supernatant Liquor After Settling 18 Hr	
	Total	Paper Filtrate	Total	Paper Filtrate
1	7.70	1.70	2.70	1.50
2	5.30	1.90	2.35	1.70
3	7.20	1.90	2.70	1.70
4	8.40	2.70	3.25	2.00
5	7.00	2.05	2.60	1.70
6	7.40	2.15	2.60	1.90
7	7.00	2.20	2.60	1.70
8	6.60	1.80	2.30	1.30
9	7.50	1.80	2.35	1.40
10	5.90	1.80	2.50	1.69
11	7.30	1.70	2.45	1.69
12	7.00	1.50	2.25	1.25
13	6.30	1.50	2.20	1.35
14	7.90	1.90	2.70	1.80
15	6.50	1.70	2.35	1.35
Avg	7.00	1.89	2.53	1.59

TABLE IV.—Effect of Biological Activity on the Iron Content of Sewage During Sedimentation

Run No.	Iron Content (mg/l)		
	Unsettled Sewage	Supernatant Liquors After Settling 18 Hr	
		Unsterilized	Sterilized
1	7.85	2.80	3.25
2	5.65	2.15	2.15
3	5.20	2.15	2.35
4	6.25	2.30	2.35
5	7.85	3.15	3.30
6	5.30	2.00	2.20
7	4.45	2.00	2.45
8	5.15	2.00	2.10
9	4.25	2.10	2.20
10	5.75	2.95	2.85
11	8.50	3.50	3.75
12	6.75	2.00	2.10
13	6.40	1.85	2.10
14	7.85	2.30	2.50
15	5.60	1.90	2.00
16	4.40	1.30	1.50
Avg	6.08	2.28	2.45
Removal (%)	—	63	60

Chemical Precipitation

In studying the effect of chemical precipitation on the iron content of sewage three precipitants were employed; lime, sulfuric acid, and aluminum sulfate. One-liter samples of sewage were precipitated with 400 mg/l of the respective precipitants since in each case this is the minimum dosage required to give reasonably complete precipitation. After settling for 18 hr the supernatant liquors were siphoned off and their iron contents determined. For comparison, determinations were also made on samples which had been settled without chemical treatment.

Since commercial aluminum sulfate contains a certain amount of iron, comparative experiments were made using the pure and commercial reagents. The results presented in Table V show that quiescent settling without precipitation removed about two-thirds of the iron present in the sewage while both lime

TABLE V.—Effect of Chemical Precipitation on the Iron Content of Sewage

Run No.	Iron Content (mg/l)					
	Unsettled Sewage	Supernatant Liquors				
		After 18 Hr	After Chemical Precipitation and Settling 18 Hr			
			CaO	H_2SO_4	$Al_2(SO_4)_3 \cdot 18\ H_2O$	
					Pure	Commercial
1	8.10	3.15	0.14	3.10	0.28	0.48
2	8.50	3.15	0.30	2.65	0.18	0.20
3	7.20	2.35	0.26	2.80	0.14	0.20
4	6.90	2.60	0.12	2.60	0.08	0.18
5	7.80	2.90	0.32	2.90	0.30	0.64
6	9.00	3.10	0.28	3.40	0.30	0.60
7	5.60	2.05	0.24	2.15	0.14	0.16
8	9.80	3.45	0.38	2.95	0.20	0.32
9	6.00	1.95	0.20	2.05	0.14	0.24
10	6.30	2.80	0.26	2.80	0.32	0.50
11	6.90	2.55	0.28	3.10	0.18	0.26
12	7.20	2.50	0.26	2.45	0.18	0.24
13	6.50	2.45	0.26	2.45	0.14	0.20
14	6.00	2.30	0.24	1.90	0.10	0.14
15	5.30	2.35	0.16	2.45	0.36	0.52
16	8.70	2.80	0.32	2.95	0.42	0.72
17	5.90	2.30	0.24	2.20	0.30	0.44
Avg	7.16	2.63	0.25	2.64	0.22	0.36
Removal (%)	—	63	97	63	97	95

and aluminum sulfate additions resulted in the removal of about 95 per cent, the iron present in the commercial aluminum sulfate having a detectable but insignificant effect.

Precipitation with acid gave somewhat variable results. In some experiments acid precipitation seemed to have little effect on the iron content as compared with plain sedimentation while in others acidification appeared to take a certain amount of iron into solution (Experiment Nos. 3, 6, and 11) or to cause some precipitation (Experiment Nos. 2, 8, and 14).

Biological Filtration

Iron content changes during the biological filtration of sewage were investigated by determining the iron contents of the 24-hr composite samples of settled sewage fed to a battery of filters, the unsettled filter effluent, the supernatant liquor resulting from an hour's quiescent settling of the filter effluent, and the paper filtrate from the filter effluent.

The results given in Table VI show that there is no retention of iron in the filters and that about 80 per cent of the iron in the filter effluent is contained in the humus solids, the remaining 20 per cent being present in the liquor.

Activated Sludge Treatment

The effect of activated sludge treatment on the iron content of sewage was studied by determining the amount present in composite samples of settled sewage fed to the four different aeration plants (diffused air, simplex, bio-aeration, and Kessener) installed at Davyhulme Sewage Works, Manchester,

TABLE VI.—Effect of Biological Filtration on the Iron Content of Sewage

Run No.	Iron Content (mg/l)			
	Filter Feed	Filter Effluent		
		Unsettled	Supernatant Liquor After Settling 1 Hr	Paper Filtrate
1	2.95	3.05	1.26	0.60
2	3.10	2.65	1.10	0.60
3	3.70	3.90	1.22	0.62
4	3.10	3.25	1.20	0.56
5	3.40	3.75	1.20	0.64
6	3.25	3.50	1.38	0.52
7	2.95	3.25	1.04	0.54
8	3.40	3.50	1.48	0.74
9	3.30	3.15	1.04	0.68
10	3.50	3.75	1.14	0.70
11	3.75	3.90	1.66	0.80
12	3.80	3.60	1.48	0.86
13	3.45	3.85	1.32	0.78
14	3.90	4.35	1.60	0.68
15	3.05	3.15	1.20	0.62
16	3.70	3.55	1.52	0.84
Avg	3.39	3.51	1.30	0.67

and the settled effluents therefrom. The results in Table VII show that activated sludge treatment removes about 80 per cent of the iron present in the settled sewage, the remaining 20 per cent passing out with the effluent.

PHOSPHATES

Phosphates are often a component of synthetic detergents and a knowledge of the changes in phosphate concentrations during sewage treatment is likely to become of increasing importance in the future. As there is little published information available on the subject a study was made at Salford of phosphate changes during sedimentation, chemical precipitation, biological filtration, and activated sludge treatment.

Analytical Technique

Small amounts of phosphates can be determined colorimetrically by combining them with ammonium molybdate to form ammonium phospho-molybdate which is then reduced by a suitable reducing agent to give "molybdenum blue"—an intensely colored reduction product of uncertain composition. For this purpose Denigès (2) used stannous chloride.

The intensity of the color produced is governed by: (a) the degree of acidity of the solution; (b) the amount of reducing agent added; and (c) the reduction period.

Sewage, however, may contain silicates from silicated detergents and although silico-molybdates are reduced to molybdenum blue in the same way as phospho-molybdates they are only formed in weakly acid solution so that by having the solution sufficiently acid there is no interference from silicates. Moreover, unless the solution is sufficiently acid reduction of the excess ammonium molybdate itself occurs but if it is too acid reduction of the phospho-molybdate is inhibited (3).

It was found that by having 0.5 ml

TABLE VII.—Effect of Activated Sludge Treatment on the Iron Content of Sewage

Run No.	Iron Content (mg/l)				
	Settled Sewage Feed	Settled Effluent from Aeration Plants			
		Diffused Air	Simplex	Bio-aeration	Kessener
1	9.9	2.30	2.65	2.60	3.90
2	10.3	1.25	2.00	2.35	2.85
3	11.9	1.20	1.20	1.55	2.35
4	12.4	2.00	1.40	2.10	2.05
5	11.3	2.00	1.50	1.65	1.85
6	13.8	1.80	1.65	1.70	2.45
7	5.1	1.35	1.25	1.25	1.65
8	5.8	1.35	1.20	1.45	1.50
9	6.6	1.20	1.10	1.20	1.70
10	11.6	1.40	1.55	1.45	1.85
11	8.4	1.75	1.95	1.65	1.85
12	11.0	1.80	2.60	1.80	1.50
Avg	9.84	1.62	1.67	1.73	2.12
Removal (%)	—	84	83	82	78

TABLE VIII.—Effect of Sedimentation on the Phosphate Content of Sewage

No.	Phosphate Content as P (mg/l)	
	Tank Influent	Tank Effluent
1	6.80	5.05
2	5.70	4.15
3	5.30	4.45
4	5.20	4.15
5	5.20	3.70
6	6.30	4.35
7	4.90	4.25
8	4.90	3.60
9	5.20	4.12
10	4.90	4.20
11	5.95	5.30
12	6.60	5.10
13	5.30	4.20
14	6.50	4.25
15	5.70	4.55
16	6.90	4.60
17	6.00	4.90
Avg	5.73	4.41
Removal (%)	23	

of concentrated sulfuric acid present, adding 1.0 ml of ammonium molybdate solution (5 per cent w/v in 5N H_2SO_4), 1.0 ml of freshly prepared stannous chloride (0.5 per cent w/v in 10-per cent v/v HCl), making to 100 ml, and allowing a reduction period of 10 min, the intensity of the color developed was proportional to the phosphate content without any interference from silicates.

Hence to determine phosphates in sewage Denigès' method was adapted so as to ensure the correct degree of acidity. A suitable volume of sample (100 or 250 ml) was digested with 5 ml of concentrated sulfuric acid and made up to 250 ml of a clear solution. Twenty-five milliliters of this solution (thus containing 0.5 ml of sulfuric acid) were then used for the colorimetric determination to which 1 ml of ammonium molybdate and 1 ml of stannous chloride were added. After diluting to 100 ml and allowing a reduction period of 10 min the phosphate content was determined photo-electrically using red light of 675 mμ wave length.

Sedimentation

The change in phosphate content effected by sedimentation was investigated by determining the amount present in the normal 24-hr composite samples of tank influent and tank effluent. The results given in Table VIII show that tank treatment removes about 25 per cent of the phosphates present in the original sewage.

In order to determine if the biological activity which occurs during settling has any influence on the removal of phosphates, comparative experiments were made using sterilized and unsterilized samples. For each of these experiments the phosphate content of a sample of sewage was determined. The sample was then divided into two 1-liter portions one of which was sterilized by the addition of a few

TABLE IX.—Effect of Biological Activity on the Phosphate Content of Sewage During Sedimentation

Run No.	Phosphate Content as P (mg/l)		
	Unsettled Sewage	Supernatant Liquors After Settling 18 Hr	
		Unsterilized	Sterilized
1	5.80	4.50	4.70
2	5.40	3.90	4.20
3	5.15	4.20	4.10
4	7.20	4.70	4.55
5	4.90	3.60	3.35
6	6.90	5.30	5.20
7	6.90	4.35	4.55
8	6.70	4.70	4.85
9	7.80	5.95	5.75
10	9.00	6.80	6.80
11	6.20	4.65	4.75
12	6.30	4.70	4.85
13	6.00	3.75	3.80
14	6.50	4.25	4.35
15	8.90	3.00	2.85
16	7.00	4.25	4.20
Avg	6.67	4.54	4.55
Removal (%)	—	32	32

drops of a saturated solution of mercuric chloride. The two portions were then allowed to settle for 18 hr when the supernatant liquors were siphoned off and their phosphate contents determined. The results in Table IX show that the removal of phosphates during settling is not affected by the biological activity which occurs.

Chemical Precipitation

The three precipitants employed in the iron experiments (lime, sulfuric acid, and aluminum sulfate) were used in the phosphate tests and at the same concentration, i.e. 400 mg/l. After settling for 18 hr the supernatant liquors were siphoned off and their phosphate contents determined. For comparison, determinations were also made on samples which had been settled without chemical treatment.

TABLE X.—Effect of Chemical Precipitation on the Phosphate Content of Sewage

Run No.	Phosphate Content as P (mg/l)				
	Unsettled Sewage	Supernatant Liquors			
		After Settling 18 Hr	After Chemical Precipitation and Settling 18 Hr		
			CaO	H_2SO_4	$Al_2(SO_4)_3 \cdot 18\ H_2O$
1	4.60	3.35	0.72	3.70	0.34
2	5.10	3.45	0.72	3.45	0.44
3	5.50	3.80	0.62	3.90	0.40
4	5.80	3.75	0.52	4.10	0.26
5	6.80	4.95	0.84	5.20	0.44
6	5.60	3.70	0.76	3.70	0.32
7	6.10	4.35	0.82	4.35	0.38
8	9.40	6.75	0.84	6.80	0.56
9	5.40	3.85	0.58	4.00	0.38
10	6.30	4.60	0.68	5.05	0.40
11	6.40	4.45	0.76	4.70	0.36
12	6.60	4.70	0.82	5.05	0.44
13	5.90	4.10	0.88	4.45	0.48
14	7.80	5.20	0.98	5.40	0.38
15	6.50	4.75	0.70	4.80	0.40
Avg	6.25	4.38	0.75	4.58	0.40
Removal (%)	—	29	88	27	94

TABLE XI.—Effect of Biological Filtration on the Phosphate Content of Sewage

Run No.	Phosphate Content as P (mg/l)			
	Filter Feed	Filter Effluent		
		Unsettled	Supernatant Liquor After Settling 1 Hr	Paper Filtrate
1	5.05	4.25	3.35	2.80
2	4.15	3.85	3.30	2.90
3	4.45	4.00	2.90	2.55
4	4.15	3.65	2.80	2.35
5	3.70	3.40	2.75	2.40
6	4.35	3.85	3.20	2.60
7	4.25	3.35	2.75	2.45
8	3.60	2.90	2.30	2.05
9	4.15	3.55	2.65	2.35
10	4.20	3.40	2.75	2.25
11	5.10	4.25	3.40	2.90
12	4.20	3.65	2.70	2.30
13	4.55	4.00	3.20	2.75
14	4.60	3.95	3.30	3.00
15	4.90	4.25	3.35	2.95
Avg	4.36	3.75	2.98	2.57

TABLE XII.—Effect of Activated Sludge Treatment on the Phosphate Content of Sewage

Run No.	Phosphate Content as P (mg/l)				
	Settled Sewage Feed	Settled Effluent from Aeration Plants			
		Diffused Air	Simplex	Bio-aeration	Kessener
1	5.30	1.00	1.95	1.65	1.50
2	4.80	0.90	1.10	1.50	1.55
3	5.50	1.50	1.65	1.70	1.95
4	3.30	0.90	0.70	0.85	1.00
5	6.10	1.45	1.20	1.30	1.40
6	5.20	1.15	0.80	0.95	1.35
7	4.40	1.75	1.55	1.85	1.85
8	5.10	2.20	2.10	2.20	2.05
9	5.60	2.65	2.70	2.65	2.75
10	5.00	1.20	0.90	1.30	1.75
11	5.40	1.80	1.70	1.95	2.15
12	6.00	1.50	1.85	1.85	1.65
Avg	5.14	1.50	1.52	1.65	1.75
Removal (%)	—	71	70	68	64

The results in Table X show that both lime and aluminum sulfate remove about 90 per cent of the phosphate present in the sewage but acid precipitation appears to take a small proportion into solution.

Biological Filtration

The effect of biological filtration on the phosphate content of sewage was investigated by determining the amount of phosphate present in the 24-hr composite samples of settled sewage fed to a battery of percolating filters, the unsettled filter effluent, the supernatant liquor resulting from an hour's quiescent settling of the filter effluent, and the paper filtrate from the filter effluent.

The results are given in Table XI and show that only about 86 per cent of the phosphate in the filter feed was recovered in the filter effluent and of that which was recovered 31.5 per cent resides in the humus solids.

Activated Sludge Treatment

The fate of phosphate in the activated sludge process was studied in the same way iron changes were studied. The results in Table XII show that activated sludge treatment removes about 65 to 70 per cent of the phosphate present in the settled sewage, the remainder passing out with the effluent.

Acknowledgment

Thanks are due to the chairman and members of the Sewage Committee of the Salford City Council for permission to publish the results of these investigations and to Mr. J. McNicholas, General Manager of the Manchester Corporation Rivers Department, for cooperation in the supply of samples from the activated sludge plants at Davyhulme.

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TIPS AND QUIPS

Treatment of Electroplating Wastes *

Methods of treatment in general use for different types of wastes are as follows:

1. Acid and metal salts. Addition of alkali to raise the pH to about 8 to 8.5 neutralizes free acid and precipitates the metals as hydroxides or basic salts which can be settled as a sludge. Lime in the form of a suspension in water is the alkali usually used but if circumstances demand it the more expensive soda ash or even caustic soda can be employed. Neutralization can be done quite well in a continuous-flow plant and if the pH has to be kept within narrow limits the amount of alkali added can be controlled by an automatic pH controller.

2. Chromic acid and chromates. Chromic acid and chromates are not removed by reaction with the common alkalis because sodium and calcium chromates are soluble in water. The way over this difficulty is to reduce the hexavalent chromium in acid solution to a trivalent salt from which chromic hydroxide is precipitated on making the solution alkaline. The reducing agent used has, until recently, been ferrous sulfate, but much sludge is produced on subsequent addition of alkali because the added iron is pre-

* *Notes on Water Pollution* (Dec. 1958).

cipitated with the chromium. Sulfur dioxide and sulfites are now coming into use; the advantage is that less sludge is produced but a possible disadvantage is that any excess of sulfur dioxide imparts an oxygen demand to the treated liquid.

Mineral acids and their metal salts do not interfere with the reduction or precipitation stages of treatment, so that segregation of chromate wastes is not necessary.

3. Cyanides. Cyanides are also not removed by addition of the common alkalis and therefore need special treatment. Addition of ferrous sulfate and lime precipitates complex cyanides of iron and effects a partial removal of cyanide; the residual cyanide in solution may range from about 5 mg/l in very favorable circumstances to about 20 mg/l under unfavorable conditions. For complete destruction of cyanide it is best to use chlorination with either sodium hypochlorite solution or chlorine gas plus caustic soda solution to raise the pH value to about 11; in more acid solutions hydrolysis of the cyanogen chloride first formed is slow and unwanted reactions occur. Although chlorination costs more for chemicals it is now the more popular process; one of its advantages is that much less sludge is produced than in the ferrous sulfate method. To obtain satisfactory control of the chlorination process it is best carried out by a batch method with final removal of excess chlorine and neutralization of alkalinity.

Nickel interferes with both the ferrous sulfate and the chlorination process and as this metal is usually present in the mixture of wastes from a plating shop it is advisable to segregate cyanide wastes for separate treatment.

Ripley Reject

The joint newsletter of the Kansas Section of AWWA and the Kansas SIWA discloses that the luckiest man in Kansas, if not the entire United States, is T. R. Higgins, sewage treatment plant operator at Haviland, Kans.

While checking the primary clarifier Mr. Higgins' new glasses (in their case) dropped out of his pocket into the basin. This, of course, was sad. But later on Mr. Higgins got another headache when the sludge pump stopped. Yep, you guessed it—the glasses, unbroken, were lodged in the ball valve.

Pollution Law Upheld in New York

The February newsletter of the New England Interstate Water Pollution Control Commission reports that a state's right to make municipalities build waste treatment works regardless of cost has been upheld in two recent test cases in New York. Utica, whose population is over 100,000, was ordered to build treatment facilities and Waterford, a community of 3,000, was told that the high cost of pollution abatement was no excuse for delaying construction of needed treatment works.

Even though these decisions were based on New York law, they establish precedents which will be cited elsewhere.

The New York Court of Appeals decided both cases on 6 to 1 votes. Speaking for the majority, Judge C. W. Froessel declared that modifying water quality standards because of local costs "is another way of saying that a physician may not diagnose a serious disease as such if the patient cannot afford the cost of the cure."

California Committee Report on Correspondence Courses *

Members of the California Sewage and Industrial Wastes Association have shown much interest in correspondence courses in sewage treatment. This year, a committee under the chairman-

* From the CSIWA Newsletter, April 1959.

ship of Jack Betz studied the need for and the possibility of establishing such a course. Questionnaires were sent to FSIWA member associations and personal discussions were held with local section members. Twenty-nine of the member associations replied; six had experience with a correspondence course. Following is a summary of the report which was presented to the Governing Board of the CSIWA.

1. *Does the membership desire a correspondence course?*

There is no great desire for a correspondence course. The lack of need for such a course is due to the existence of other available training, principally through the junior colleges in many areas. In areas remote from the junior colleges, more interest would probably be expressed.

2. *What subjects would be offered if such a course were given?*

Basic mathematics is necessary and then general sewage treatment including maintenance.

3. *Should the courses be self-sustaining or subsidized by the Association?*

Unless an increase in general dues is made, the CSIWA treasury cannot support this program to any extent. If no underwriting from public agencies is possible (and this has not been investigated), the cost may be quite high and would become an important factor in limiting the participation.

4. *How should the course be designed? Special syllabus or existing text?*

A special syllabus designed for home study would be the best answer. Use of existing material of this nature as edited by a CSIWA committee might be feasible.

5. *How should the course be administered?*

The majority of the committee feels that a paid administrator would be required to insure that the program is carried forward promptly. The workload would be too great for a volunteer worker. It was also pointed out that unless the lessons were graded and returned promptly, student interest would undoubtedly lag. National experience has been almost entirely limited to administration through a state university.

6. *Should the course be tied in with certification in some way?*

There is feeling that the course completion should assist operators in becoming certified. The knowledge gained would, of course, aid in passing a certification examination, but some additional incentive would probably promote added interest in the correspondence course.

In view of this and other information, the Governing Board felt that the chances for a successful correspondence course were not very good and would not be pursued at this time. Existing educational programs should be extended and improved. The facilities of the State educational institutions are a possible aid which should be explored.

You can tell the character of every man when you see how he receives praise.

SENECA (8 B.C.–A.D. 65)

Lease-Purchase Plan

Infilco, Inc., has recently made arrangements for the leasing of equipment to customers in the U. S. on a lease-purchase contract. An important advantage claimed for this sort of transaction is the opportunity to make deferred payments not otherwise available under standard terms. For nonmunicipal customers, there is also an opportunity for realizing a tax deduction equal to the cash outlay on all lease rental payments. For municipalities and other public bodies, lease payments may be taken out of current revenues or other sources of funds and thus possibly avoid the necessity of issuing bonds.

Federation Affairs

DAZZLING DALLAS BECKONS!

Preparations have reached a high pitch for the 32nd Annual Meeting of the Federation in Dallas, Texas, October 12–15, 1959. The meeting will be the culmination of many years of desire on the part of the Texas Member Association to be the Federation's Host.

The placing of the meeting in Dallas is in reality the invasion of an area not previously served by a Federation meeting and no future meeting, at least through 1963, is scheduled for the South Central or Southwestern United States. Much of the delay in reaching this area in general, and Texas in particular, has been the lack of appropriate Federation meeting facilities. With growing demands each year, meeting facilities with space for exhibits, technical sessions, and social functions are not plentiful.

The technical program has been prepared to interest those from all endeavors and there will be 11 sessions packed with technical know-how. Exhibit space is a virtual sellout in spite of the generous space made available by the Dallas Memorial Auditorium.

The Local Arrangements Committee of the Sewage and Industrial Wastes Section of the Texas Water and Sewage Works Association has been engaged in completely detailed planning of the local events which will contribute so much to the meeting. With the wealth of attractions in Dallas, the committee has had to choose carefully from those it considers of maximum interest to the Federation membership. For example, the Annual Texas State Fair will be in progress—and don't miss the ride on the monorail car!

The Local Arrangements Committee Chairman is Henry J. Graeser, Superintendent of the Dallas Water and Sewer Department. The committee is made up of the following, each of whom acts as chairman of his subcommittee: D. F. Smallhorst, Hotel Arrangements and Technical Sessions; R. G. Ford, Finance; E. F. Smith, Jr., Registration; R. E. Morris, Jr., Entertainment; Cecil Williams, Inspection Trips; Ben L. Grimes, Host Committee; and Mrs. Henry J. Graeser, Ladies Entertainment.

The plan of registering in advance of the meeting, introduced for the 1957 meeting, will be continued this year. It is hoped that the preregistration cards may be sent to all membership, but should this not be possible, these will be available on request from the Federation office. If you submit such a card with a remittance, your tickets, badges, and program would be ready for you upon arrival at the registration area in Dallas. One registration card is necessary for each person except that a man and wife may register on a single card. Regular registration facilities will be open Sunday afternoon for registration or for claiming your preregistration envelope.

The general meeting announcement listing subjects and participants was sent to all Federation members of record in July. Hotel reservation cards were included with this mailing. Your early submission of this reservation request will help assure you of a room in accordance with your wishes. Those who cannot be accommodated at the Statler Hilton will be placed in nearby hotels. Additional information may be obtained from the Federation office. R. E. F.

News and Notes

Of Persons and Activities in the Wastewater Field

Dr. George E. Symons has reopened his consulting office on a full-time basis in Larchmont, N. Y. As he did in 1951–56, "Doc" will offer services as a consultant in the field of sanitary engineering and as a consulting editor and writer. He was recently appointed as a Special Consultant to the Engineering Services Division of the U. S. Public Health Service.

Dr. Gerald H. Teletzke was recently appointed to the post of Director of Sanitary Engineering Research, the Eimco Corporation, with headquarters at Palatine, Ill. He leaves Purdue University where he was Associate Professor of Sanitary Engineering.

Walter C. Anderson, Superintendent of the Cranston, R. I. Sewage Treatment Plant, was recently appointed to membership on the New England Interstate Water Pollution Control Commission.

A. J. Steffen, Sanitary Engineer for Wilson and Co., Chicago, has been appointed Chairman of the American Meat Institute's Sanitation Committee, which studies and reports on technical advancements and problems of sanitation in the industry.

Walter W. Saxton has resigned his position as Chief Engineer of the Washington State Pollution Control Commission to accept a position with **Stevens and Thompson** in Seattle.

Dr. C. Fred Gurnham, Professor and Head of the Department of Chemical Engineering at Michigan State University, has accepted the position of Editor of *Industrial Wastes*, replacing **Professor Don E. Bloodgood,** who has been forced by the pressure of his duties at Purdue University to relinquish the post.

G. R. Herzik, Jr. was appointed Director of the Division of Sanitary Engineering of the Texas State Department of Health.

Professor Harold E. Babbitt will be Visiting Professor of Civil Engineering at Iowa State University, Ames, during the academic year of 1959–60 when **Professor E. Robert Baumann** is in England. Professor Babbitt leaves a similar post at the University of Missouri for this new assignment.

L. W. Roznoy, formerly Technical Consultant, Celanese Corporation, has been appointed Director of Air and Water Pollution Control for Olin Mathieson Chemical Corporation, New York.

Frank A. Marston, of Metcalf and Eddy, Boston, has been named the official nominee for President of the American Society of Civil Engineers for the year beginning in October.

Cincinnati dedicated its new Mill Creek Sewage Works June 18. The District of Columbia dedicated its new secondary treatment facilities July 6.

The name of **Engineering Office of Clyde C. Kennedy,** San Francisco, Calif., has been changed to **Kennedy Engineers.**

Gilbert T. Bowman has been elected a Vice-President of Rockwell Manufacturing Company's Meter and Valve Division where he will be in charge of the International Division and Petroleum and Industrial Division.

Reid S. Parramore, formerly Consultant on Waste Treatment Plant Design and Construction for DuPont, has been appointed Regional Engineer for Yeomans Brothers Company. His headquarters will be in Wilmington, Del.

Walter E. Merrill has retired after over 40 years of service with the Massachusetts State Department of Health.

Bogert and Childs, with offices in New York, Hackensack, N. J., and South Norwalk, Conn., announced that since the recent retirement of Fred S. Childs the firm will be operated under the name of **Clinton Bogert Engineers.**

George E. O'Keefe, formerly with the Control Office of the New York State Health Department, has recently been appointed Director of Environmental Sanitation of the Rockland County Health Department.

Reviews and Abstracts*

The Construction of Biological Film in a Percolating Sewage Filter. By G. C. Ware and J. E. Loveless. *Jour. Appl. Bacteriol.* (Brit.), **22**, 2, 308 (1959).

A small glass microfilter to simulate the surface of medium in a trickling filter was constructed from a microscope slide to which was cemented thin strips of glass covered by a cover glass cemented in position, forming a channel through which sewage was allowed to run continuously from a small reservoir attached to the slide. Sewage was aerated and agitated as it was delivered to the reservoir. The rate of flow through the microfilter was 100 ml/hr giving a linear flow rate of 5 cm/sec through the channel. This assembly with an effluent removal device was mounted on the stage of a microscope for visual and photographic observations. The flow was laminar. The liquid in contact with the surfaces remained almost at rest. Organisms in sewage were soon deposited on the upper and lower glass surfaces of the filter. Many of these organisms first deposited, degenerated, and were lost due to some unsuitable environment. Sometimes they remained in position without movement or growth. After 3 to 4 hr several small organisms had invariably deposited at different points in the field which divided at once without further migration. These primary invaders had identical morphology. They multiplied and formed colonies in contact with the surface seldom more than one organism thick. Shortly after, another much larger organism always appeared, but in contrast with the primary invader, it did not adhere firmly to the surface but migrated slowly downstream, dividing as it went and until it came in contact with a group of primary invaders to which it adhered firmly. The resulting association enlarged and either joined another association or having attained a certain diameter (20 to 30 μ) started to trap solid particles from passing sewage including other bacteria. By 8 to 10 hr the community was too dense to allow free passage of sewage and proper observation. Motile protozoa could be seen after 10 hr and amoebae appeared on the glass surface an hour or two later.

The mean generation time of the pioneer organism was 104 min and that of the secondary invader 94 min.

Cultures of *E. coli*, *S. aureus*, and a filamentous organism were treated with 0.01-per cent Fluolite 180 which imparted a brilliant blue fluorescence. These were added to the sewage fed to a microfilter which had been operating for 6 hr. These organisms were not seen to enter the association, but remained on the surface and edge of the association where they formed fluorescent clones.

H. Heukelekian

The Relationship Between Maximum Oxygen Solution Rates in a Bacterial Culture and in a Sodium Sulfate Solution Under Comparable Aeration Conditions. By S. J. Pirt and D. S. Callow. *Jour. Appl. Bacteriol.* (Brit.), **21**, 2, 206 (1959).

The rate of oxygen uptake σ_s of sodium sulfite solution containing copper ions was measured. The rates of oxygen uptake in continuous cultures of *Aerobacter aerogenes* were also measured σ_c.

The ratios of oxygen solution rate in the culture to the oxygen solution rate by the sulfite method σ_c/σ_s ranged from 0.7 at low rates of solution in sulfite to 0.5 for higher rates. The fall in the ratio with increase in σ_s was not accounted for by

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N.W., Washington 16, D. C.

change in the bacterial concentration. The evolution of CO_2 did not affect the oxygen solution rate in the culture.

To satisfy the oxygen demand of the culture, aeration conditions must be such that oxygen solution rate by the sulfite method is 1.4 to 2.0 times the oxygen demand.

H. HEUKELEKIAN

BOOKS, REPORTS, PAMPHLETS

Use of Radar for Ocean Current Studies. By R. A. ROBSON AND W. J. DAVY, Melbourne and Metropolitan Board of Works, 110 Spencer St., Melbourne, C. 1, Australia, Tech. Paper No. A5 (1955).

Reviews the alternative methods available for determining direction and velocity of ocean currents with radar. Descriptive material of methods and equipment is included.

The Effect of Automatic Sequence Clothes Washing Machines on Individual Sewage Disposal Systems. National Academy of Sciences, National Research Council, Washington, D. C. Publ. No. 442, 24 pp. Price, $1.50 (1956).

Proceedings of the Sixth Annual Water Symposium. College of Engineering and General Extension Division, Louisiana State University and Agricultural and Mechanical College, Baton Rouge, La. (1957).

Collection of papers presented at the annual symposium, February 19–20, 1957.

The Acid-Mine-Drainage Problem in Ohio. By E. Q. MOULTON, Engineering Experiment Station, Ohio State University, Columbus, Ohio. Bull. 166 (1957).

A report of a research program on the acid mine-drainage problem supported by the Water Pollution Control Board, Ohio State Dept. of Health. Contains an extensive annotated bibliography.

Annual Report of the Scientific Adviser for the Year 1956. Scientific Branch, Public Health Dept., London County Council, County Hall, Westminster Bridge, S. E. 1, London, England (1957).

Handbook of Selected Biological References on Water Pollution Control, Sewage Treatment, and Water Treatment. By WILLIAM MARCUS INGRAM, Robert A. Taft Sanitary Engineering Center, Public Health Service, Cincinnati, Ohio. Publ. No. 214, Rev., 95 pp. (1957).

A complete revision of the earlier edition (1953) of the handbook.

Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe. American Society for Testing Materials, 1916 Race St., Philadelphia, Pa., ASTM C76-57T (1957).

Tentative specifications for reinforced concrete culvert, storm drain, and sewer pipe, providing for coverage of larger sizes of pipes and greater strength.

Hydraulics of Culverts. By JOHN G. HENDRICKSON, JR., American Concrete Pipe Assn., Chicago, Ill. 228 pp. (1957).

A handbook on the hydraulics of reinforced concrete pipe culverts, covering the subjects of location, runoff, inlets and outlets, definitions and elementary hydraulics, and flow. Supporting charts and tables are included.

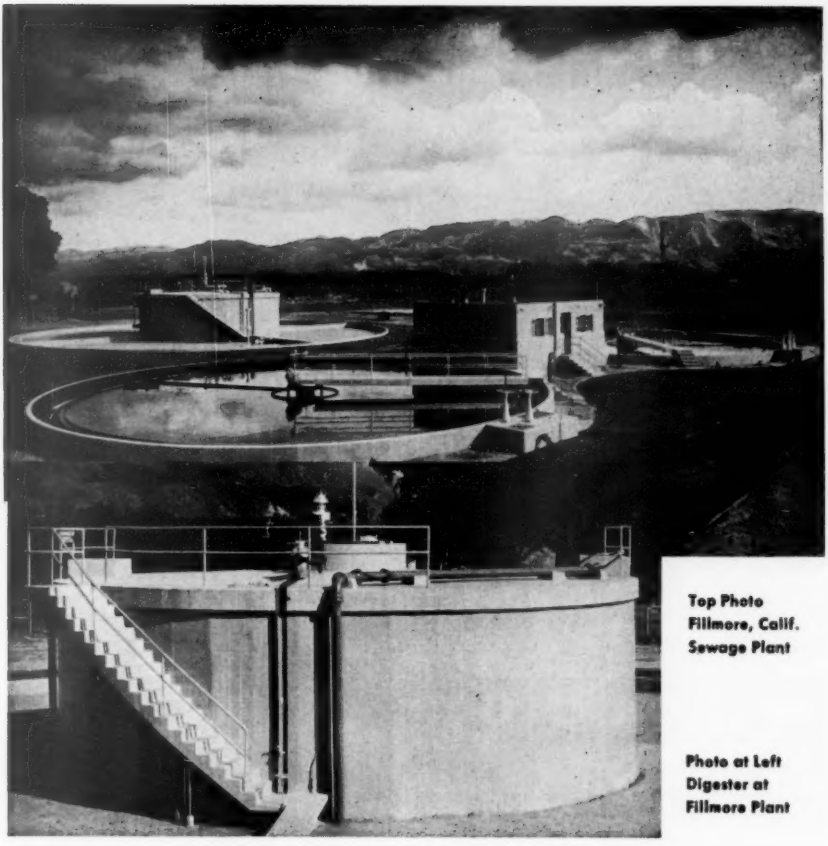
Loads and Supporting Strengths for Concrete Pipe Lines. By THOMAS K. BREITFUSS, American Concrete Pipe Assn., Chicago, Ill.

Rural Water Supply and Sanitation. By FOREST B. WRIGHT. John Wiley and Sons, Inc., New York, N. Y. Second Ed., 347 pp. Price, $5.00 (1956).

Presents in two parts: (a) the important aspects of water supply and sewage disposal for the rural home and farmstead, and (b) the important jobs in connection with installing a proper water or sewage facility. Illustrated.

Proceedings of the Fifth Southern Municipal and Industrial Waste Conference. Dept. of Public Health Engineering, School of Public Health, University of North Carolina, Chapel Hill, N. C. 261 pp. Price, $1.50 (1957).

Papers at the Fifth Southern Municipal and Industrial Waste Conference, held at University of North Carolina, Chapel Hill, N. C., April 5–6, 1956.



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The 44th Annual Meeting of the New Jersey Sewage and Industrial Wastes Association was held at the Hotel Traymore, Atlantic City, N. J., on March 11–13, 1959. In spite of heavy snows in Northern New Jersey, which held down attendance from that area, a total of 490 persons were present, including 55 ladies.

The technical sessions were well balanced and well attended. The meeting included a joint session with the Mid-Atlantic States Section of the Air Pollution Control Association. The last day of the Air Pollution Association meeting overlapped with the first day of the Association sessions.

Among the papers of particular interest were the following:

"Solids Separation from Liquid Industrial Wastes," moderated by R. W. Ockerhausen, Engineer, Technical Service, Allied Chemical and Dye Corp.

"Interrelationship Between Air and Liquid Pollution Problems," by William H. Lang, Esso Research and Engineering Co.

"Pollutional Effects of Solid Particles on Surface Water," by Sylvan C. Martin, New England Regional Engineer, USPHS.

"Physical and Chemical Behavior of Suspended Solids," by R. D. Hoak, Senior Fellow, Mellon Institute of Industrial Research.

(*Continued on page 338a*)

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"Flotation—Theory, Design, and Operation," by F. S. Gibbs, F. S. Gibbs, Inc.

"Dowpac, A New Production in the Consideration of Waste Treatment," by D. H. Moeller and E. E. Chamberlain, Dow Plastics Fabricated Products.

"Penns-Grove Sewage Treatment Plant," by Leo Savarese, Superintendent, Penns-Grove Sewerage Authority.

"Sewer Maintenance Practices," by John F. Vogler, Municipal Engineer of Sewers, City of Trenton.

"Laboratory Controls for Small Plant Operators," by Leroy Forman, New Jersey State Department of Health, and Robert Arnette, Bergen County Sewerage Authority.

"Radioactivity, A Source of Pollution," by Robert J. Budrick, Jersey City Water Works.

"General Principles of Chemical Coagulation," by M. C. Rand, Chief Chemist, Middlesex County Sewerage Authority.

"Selective Waste Recovery Systems with Pressurized Flotation," by Nicholas Zalieko, Technical Manager, Waste Treatment Division, Ralph B. Carter Co.

"Advanced Planning Assistance for Public Works," by Leslie P. Doridge, Regional Director, Community Facilities Administration, HHFA, Philadelphia, Pa.

"Recent Developments in Waste Treatment Equipment," by H. W. Gillard, Manager, Infilco, Inc.

Mark D. Hollis, FSIWA Vice-Presi-

(*Continued on page 340a*)

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Automatic Analyzer—A system for continuous automatic chemical analysis that is claimed to be able to detect trace materials down to ppb, with an accuracy of one per cent, has been announced by Technicon Controls, Inc., Chauncey, N. Y.

Pavement Breaker—A new lightweight pavement breaker which weighs 24 lb is claimed to be ideal for light utility work, trimming around manholes and steel work, and brick and blacktop removal. For further details contact the nearest Worthington dealer or the Worthington Corporation, Holyoke, Mass.

Aerator—A new aeration device has been introduced by Dorr-Oliver, Inc., Stamford, Conn. In this new unit air is supplied through a sparge ring located near the bottom of the tank. Rising air bubbles are sheared by the action of a turbine-type mixing unit located immediately above the sparge ring. The unit is described in Bulletin 7316.

pH Control—Data Sheet pH-4206 describes how a standard industrial pH meter can be used to measure the pH of sewage sludge.—Beckman Process Instruments Division, 2500 Fullerton Rd., Fullerton, Calif.

Recording Turbidimeter—Applications, principles of operation, and specification for a recording turbidimeter are described in Bulletin GET-2741-9.—General Electric Company, Schenectady 5, N. Y.

Force-Balance Transmitters—A new line of force-balance transmitters which measure and pneumatically transmit flow, differential pressure, level, and specific gravity over wide ranges, is now being manufactured by Bailey Meter Co., 1050 Ivanhoe Rd., Cleveland, Ohio. Transmitters measure over a minimum range of 0 to 2 in. of water under service pressures of up to 50 psi, to a maximum span of 0 to 2,000 in. of water under service pressures of up to 5,000 psi.

Hydraulic Pipe Cutter—According to the Wheeler Manufacturing Corporation, Ross Rd., Ashtabula, Ohio, their new hydraulic pipe cutter (Figure 1) will cut cast iron water pipe in sizes up to 12 in., terra cotta or clay tile from 6 through 36 in., and asbestos-cement pressure pipe from 6 through 10 in. To operate, the chain is wrapped around the pipe and pulled through the jaws to the nearest ring. The adjusting screw is tightened to take up the slack and hydraulic pressure is applied by hand or an electric pump. The cutter sells for $352.50.

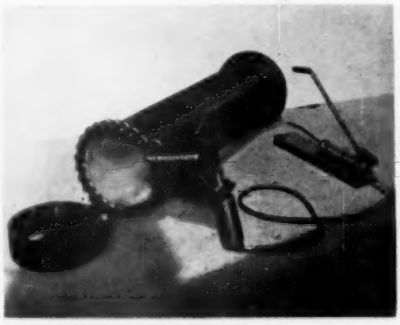

FIGURE 1.—Hydraulic pipe cutter.

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dent, extended the greetings of the Federation Headquarters. He also made the presentation of the Bedell and Hatfield Awards to Robert S. Shaw and William Stanley Applegate, respectively. Mr. Shaw's award was given for extraordinary personal service to the New Jersey Association and Mr. Applegate was honored for outstanding sewage works operation.

Officers elected for 1958–59 were:

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2nd Vice-President: John Frazee, Camden.
3rd Vice-President: James C. Lamb, III, Bound Brook.
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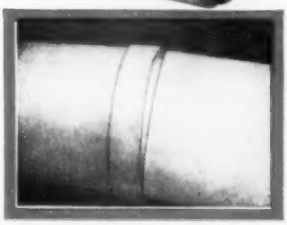

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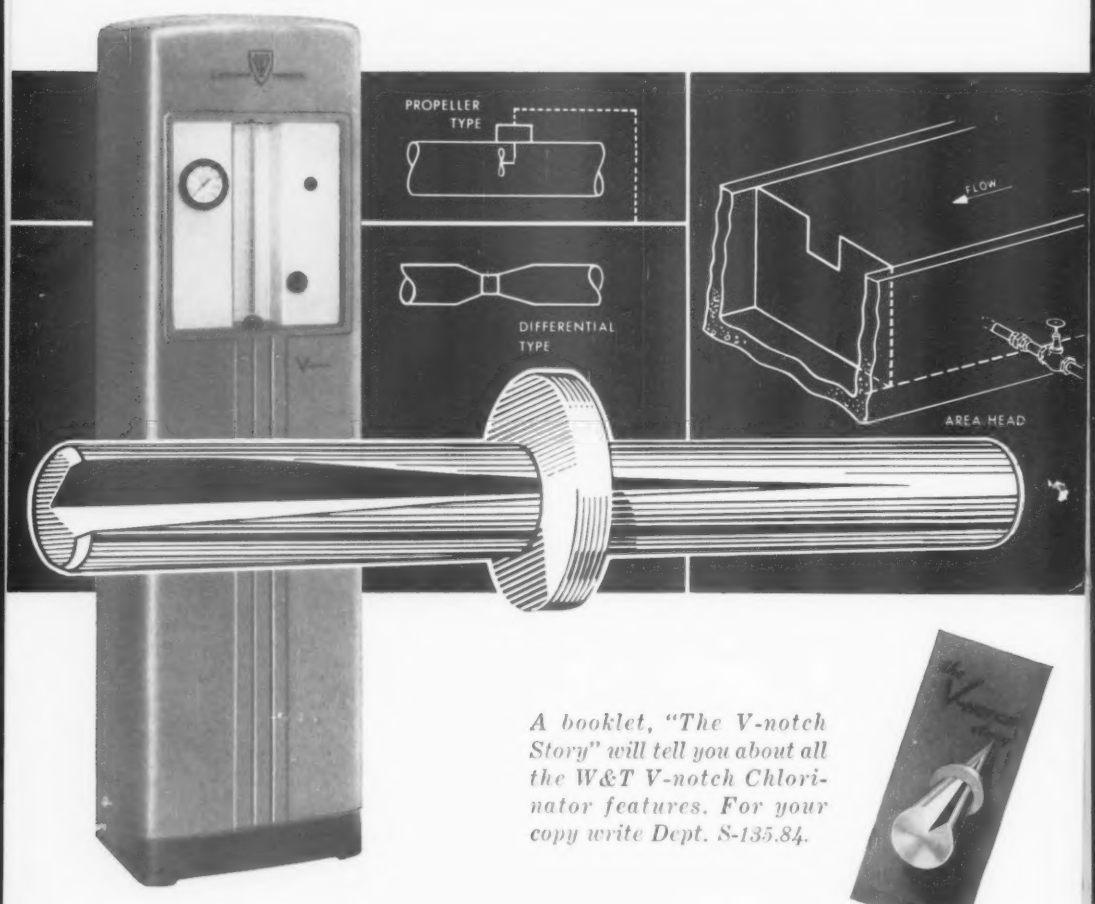

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